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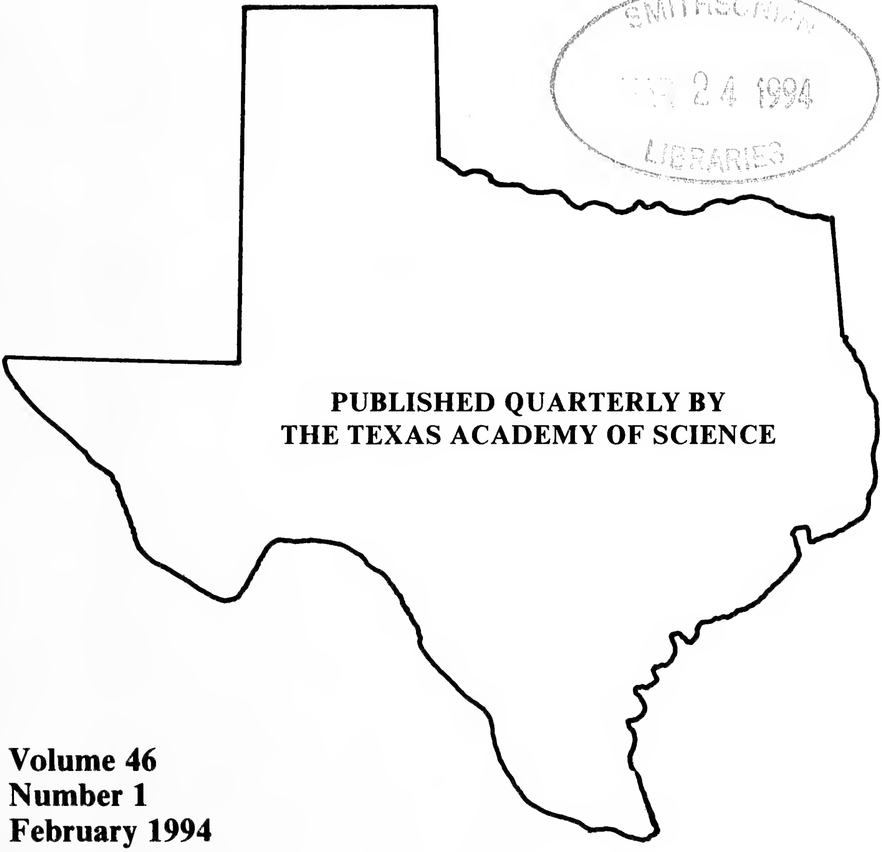

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General Notes

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SYNTHESES OF SOME 2- (2-PYRIDYL) CYCLOALKANONES

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Abstract.—Six 2-(2-pyridyl) cycloalkanones were synthesized by the condensation of morpholine enamine of the appropriate cycloalkanone with pyridine-1-oxide in the presence of benzoyl chloride. Cyclopentanone, cyclohexanone, cycloheptanone, cyclooctanone, cyclodecanone, and cyclododecanone were utilized. Hydantoin derivatives were prepared and the enol/keto ratios determined. *Key words*: enol/keto; tautomerism; hydantoin; cycloalkanones.

Our interest in enolizable ketones resulted in a recent paper reporting on the syntheses and enolization of 4-alkyl-2-(2-pyridyl) cyclohexanones (Sund et al., 1991). We believed it would be interesting to investigate a similar series of compounds in which the size of the cyclic ketone was varied from five to twelve carbons. These ketones were synthesized by condensing the morpholine enamine of the appropriate cycloalkanone with pyridine-1-oxide in the presence of benzoyl chloride (Fig. 1) (Hamana and Noda, 1965). The enamine was prepared from the requisite cycloalkanone and morpholine by a standard method and used without further characterization (Hunig et al., 1973). The compounds 2-(2-pyridyl)cyclononanone and 2-(2-pyridyl)cycloundecanone were not prepared because the requisite ketones could not be purchased at reasonable cost. The 2-(2-pyridyl) cycloalkanones were yellow to orange oils and were characterized by conversion into hydantoin derivatives (Table 1) (Henze and Speer, 1942).

Experimental Protocol and Results

All chemicals were purchased commercially (Aldrich). Elemental

Table 1. Synthesis of 2-(2-pyridyl) cycloalkanones and 6-(2-pyridyl)-1, 3-diaza-2, 4-dioxospiro [4.(4-11)] alkanes (Fig. 2).

n	yield %	Bp °C/mm	enol/keto ratio	mp,°C	yield %
1	40	118/2	3.3/1	230-232	47
2	46	135/1(a)	.4/1	258-259	45
3	50	119/0.9	5.0/1	264-266	27
4	62	118/0.5	2.5/1	203.5-205.5	82
6	60	130/0.5	1.1/1	277-278	10
8	32	145/0.5	.2/1	286-287	35

(a) reported bp 99-100/0.01 mm (Funke and Russi, 1954); bp 138-140/0.13 mm (Hamana and Noda, 1965).

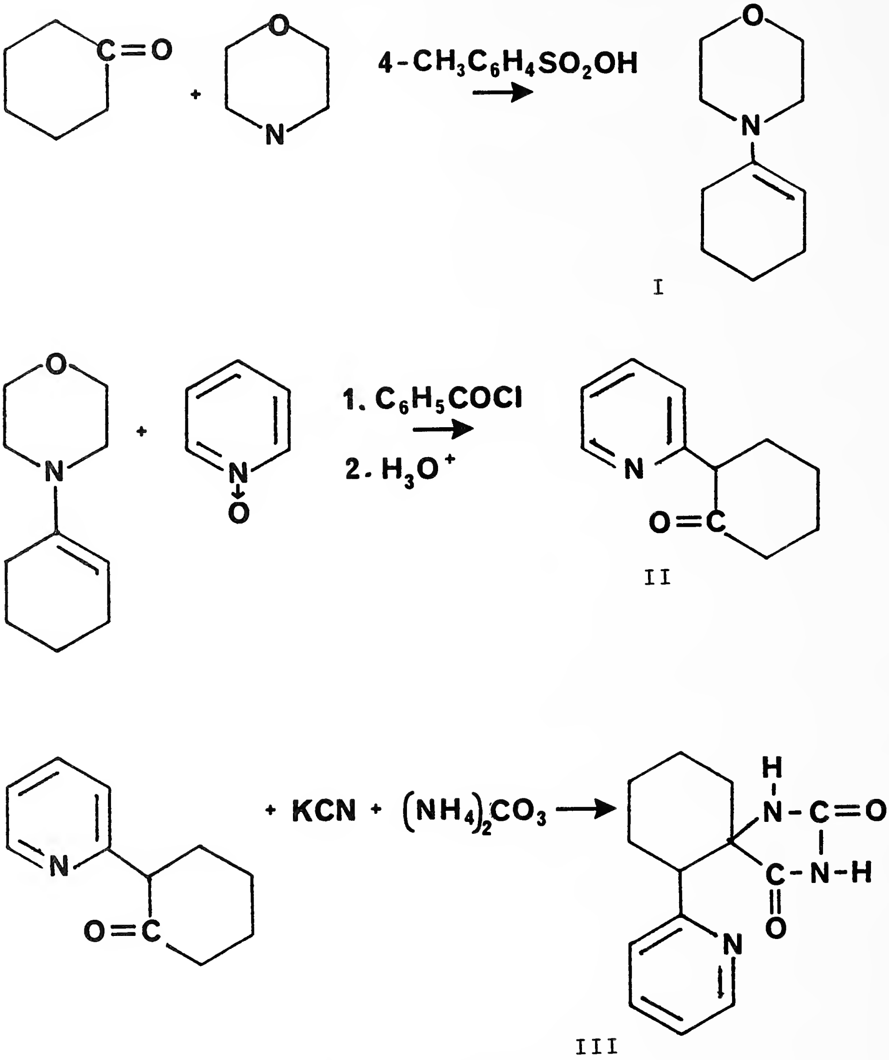

FIGURE 1. Reaction Sequence.

analyses were performed by Huffman Microanalytical Laboratories, Golden, CO 80403. The melting points were determined on a Thomas-Hoover melting point apparatus and were corrected. The yields represent single preparations and could in all probability be improved. The following example illustrates the syntheses of the 2-(2-pyridyl) cycloalkanones.

2-(2-pyridyl) cyclohexanone

In a stirred flask were placed 115 ml of chloroform and 21.9 g (0.23

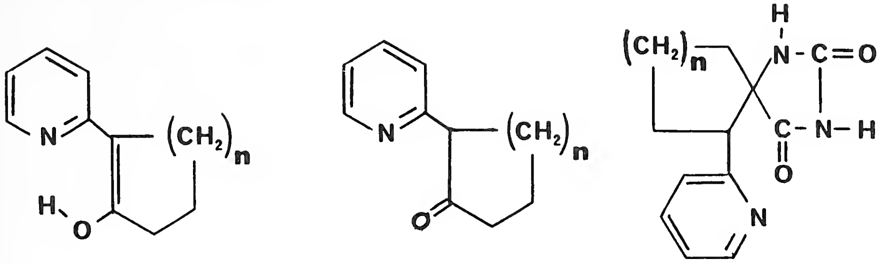

FIGURE 2. Enol (left), keto (center), and hydantoin (right).

mol) of pyridine-1-oxide. The enamine, 1-morpholino-1-cyclohexene (I), 76.8 g (0.46 mol), was added, the reaction mixture cooled in an ice bath and 38.8 g (0.28 mol) benzoyl chloride added dropwise. The reaction mixture stood for three days at room temperature. The Japanese literature suggests that some pyridine-1-benzoate forms during this period of time. The benzoate is a facile leaving group, thus facilitating the acylation of the pyridine by the enamine. At the end of this time, the reaction mixture was acidified with 20 percent HCl to a pH of 1 and the solvents removed under reduced pressure, collecting the fraction distilling at 135°C/(1mmHg). We obtained 23.6 g (46 percent yield) of 2-(2-pyridyl) cyclohexanone (II). A hydantoin, 6-(2-pyridyl)-1,3-diaza-2, 4-dioxospiro [4.5] decane (III), was prepared, mp 258-259°C. The NMR spectrum was obtained with a Perkin Elmer 90MHz R-32 spectrometer. The NMR spectrum in $DCCl_3$ showed the following characteristics: a complex series of signals at 1-4 ppm which we assigned to various aliphatic protons, the number of peaks being doubled because both enol and keto tautomers were present (Fig. 2), a multiplet at 6.9-7.7 ppm for the aromatic protons, with two sharp doublets at 8.2 ppm and 8.5 ppm due to the protons in the 6 position of the pyridine ring of the enol form and the keto form, respectively. The large change in the chemical shift for the proton in the 6 position (8.5 ppm to 8.2 ppm) is to be expected since the polarizability of the nitrogen has been greatly altered due to the hydrogen bonding of the enol isomer (Wursthorn and Sund, 1972). Tetramethylsilane was used as an internal standard; the chemical shifts are reported in ppm relative to it in all cases. The relative area of the enol proton at 8.5 ppm and the keto proton at 8.2 ppm were determined by integrading the peak areas. Several integrations were performed and the enol/keto ratio was determined to be approximately 2.4. Elemental analyses of the hydantoins for C, H, and N in agreement with theoretical values were obtained and submitted for review (Table 2).

TABLE 2. Analytical data for review, 6-(2-pyridyl)-1, 3-diaza-2, 4-dioxospiro [4.(4-11)] alkanes.

	ANALYSES					
	CALCULATED			FOUND		
n	%C	%H	%N	%C	%H	%N
1	62.33	5.67	18.17	62.17	5.78	17.88
2	63.66	6.16	17.13	63.85	6.31	16.99
3	64.85	6.61	16.20	64.85	6.68	16.02
4	65.91	7.01	15.37	65.80	7.02	15.41
6	67.75	7.69	13.94	67.22	7.78	13.74
8	69.26	8.28	12.76	69.00	8.26	12.64

DISCUSSION

One possible rationale for the observed enol/keto ratios could be based on steric considerations. Using Fischer-Hirschfelder-Taylor space filling models (Fischer) of the 2-(2-pyridyl) cyclopentanone and the 2-(2-pyridyl) cyclohexanone, the cycloalkane ring is rigid in both the enol and the keto form but steric interactions appear greater in the keto form of the cyclopentane ring and in the enol form of the cyclohexane ring thus favoring the enol form in the five membered ring and the keto form for the six membered ring. As the size of the ring increases there is a trend toward the enol/keto ratios found in 2-(2-pyridyl) alkanones which would be expected because of the increasing flexibility of the larger rings (Wursthorn and Sund, 1972).

ACKNOWLEDGMENT

We gratefully acknowledge the financial support of a Robert A. Welch Foundation departmental grant.

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BAYESIAN ESTIMATION OF POPULATION DENSITY AND VISIBILITY

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ABSTRACT.—It is assumed that a sample region may be subjected either to "exhaustive search", in which case the number of animals found is Poisson distributed with a mean proportional to the population density λ, or else a cheaper sort of "cursory search", in which case the mean count is multiplied by an unknown "visibility" parameter p, between 0 and 1. We consider Bayesian, or at least formally Bayesian, estimation of λ and p based on independent cursory searches, exhaustive searches, prior information about λ, and prior information about p. The subjects of examples treated are gallinule nests and bicycles which may or may not be visible from the street. *Key words*: population density; visibility bias; Bayesian estimation; equivalent sample information; posterior distribution.

Let A be the size of a sample region, let T be the number of animals present in this region, and let $X = T - Y$ be the number of animals which might be noticed in a cursory search. We assume that the distribution of T given λ (and p) is Poisson with mean λA. Assume, also, that the distribution of X given T and p (and λ) is binomial with parameters T and p.

The *a priori* probability density $f(\lambda,p)$ is assumed to be noninformative, or more generally to be in the form of the product of a gamma density for λ and a beta density for p. Then, the posterior density $f(\lambda,p|T)$, which becomes available if the area is searched exhaustively, is of the same (conjugate) form. Under some circumstances it may be possible to search the area cursorily and then to follow up with an exhaustive search of the same area. Then, one obtains a posterior density $f(\lambda,p|T,X)$ which is again of the conjugate form.

We assume that the results of exhaustive searches and any other experiments yielding independent information about λ and p, are absorbed into the assumed *a priori* density

$$f(\lambda,p) = \frac{e^{-\lambda a}\,\lambda^{v-1}\,a^{v}}{\Gamma(v)} \cdot \frac{p^{\alpha-1}\,(1-p)^{\beta-1}}{B(\alpha,\beta)} \qquad (1)$$

where $B(\alpha,\beta) = \Gamma(\alpha)\Gamma(\beta) / \Gamma(\alpha+\beta)$. Figure 1 depicts a double sampling scheme for which $\alpha = x+1$, $\beta = y+1$ and $v = t+1$ yields a likelihood of the form given by density (1). Therefore, density (1) may represent nothing more than a factor of the likelihood function discussed above or it may have a more thoroughly Bayesian meaning.

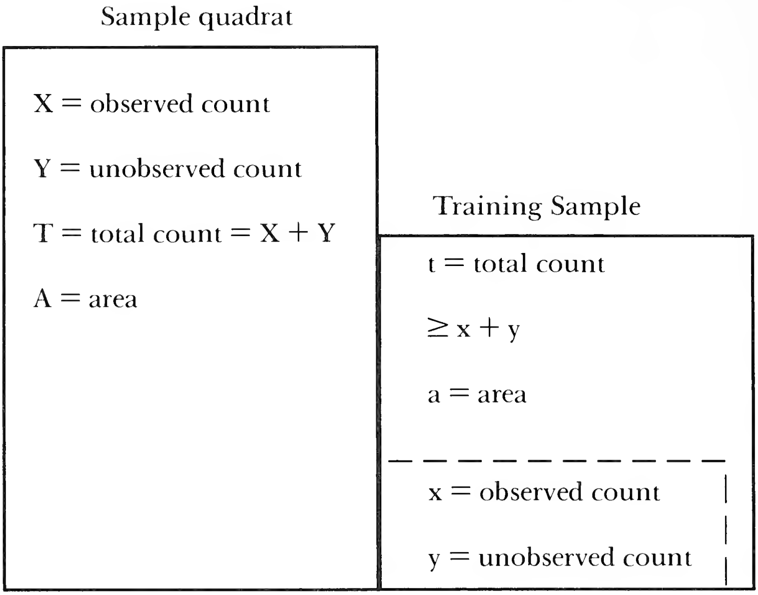

FIGURE 1. Typical Sampling Layout

In any case, we now adopt the assumption that our "prior" estimation of the parameters is to be updated by observation of X alone.

MATHEMATICAL PRELIMINARIES AND RESULTS

The formulas presented below, and much more fully in Kutran (1975), may be derived by essentially straightforward methods. The results are presented in terms of hypergeometric functions and confluent hypergeometric functions. It is of interest to note that the confluent hypergeometric function, M, yields the prior moment generating function of p from density (1).

$$M(\alpha;\alpha+\beta;z) = \int_0^1 \frac{p^{\alpha-1}(1-p)^{\beta-1}}{B(\alpha,\beta)} e^{pz}\,dp$$

$$= \sum_{k=0}^{\infty} \frac{\Gamma(\alpha+k)}{\Gamma(\alpha)} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha+\beta+k)} \frac{z^k}{k!} \qquad (2)$$

Consider the average of the cursory count, x, given p and λ; that is, $E(x|p,\lambda)$. For random p and λ, $E(x|p,\lambda) = a\,p\lambda$ is a random variable with moment generating function given by the hypergeometric function, F.

$$F(\nu,\alpha;\alpha+\beta;z) = \int_0^1 \frac{p^{\alpha-1}(1-p)^{\beta-1}}{B(\alpha,\beta)} (1-pz)^{-v}\,dp$$

$$= \sum_{k=0}^{\infty} \frac{\Gamma(v+k)}{\Gamma(v)} \frac{\Gamma(\alpha+k)}{\Gamma(\alpha)} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha+\beta+k)} \frac{z^k}{k!} \tag{3}$$

Johnson and Kotz (1969) provide an adequate discussion of the behavior of these functions. The terms in the above series are recursive and easily programmed for evaluation. Consider the k^{th} term of F(t,a;c;z), say B_k, then

$$B_k = B_{k-1} \frac{(t+k-1)(a+k-1)}{(c+k-1)} \frac{Z}{k}.$$

The prior information in (1) is now updated to include the observation X over the sample region A. Averaging out the parameters in the binomial conditional probability model for X we obtain

$$f(X) = \frac{B(X,\alpha+\beta)}{B(X,v)B(X,\alpha)} \left(\frac{A}{A+a}\right)^X \left(\frac{a}{A+a}\right)^v F(X+v,\ \beta;\ X+\alpha+\beta;\ \frac{A}{A+a})/X$$

$$X=1,2,3\ \ldots\ . \tag{4}$$

Hence, the posterior marginal distributions on the visibility p and density γ are, respectively,

$$f(p|X) = \frac{B^{-1}(X+\alpha,\beta)\ p^{X+\alpha-1}\ (1-p)^{\beta-1}}{F(X+v, X+\alpha;\ X+\alpha+\beta;\ -A/a)} (1+p\ A/a)^{-(X+v)},$$

$$0 < p < 1, \tag{5}$$

(which might be called a hypergeometric function density) and

$$f(\lambda \mid X) = \frac{a^{X+v}}{\Gamma(X+v)} \lambda^{X+v-1} e^{-a\lambda} \frac{M(X+\alpha;\ X+\alpha+\beta;\ -A\lambda)}{F(X+v,\ X+\alpha;\ X+\alpha+\beta;\ -A/a)},$$

$$y > 0. \tag{6}$$

The information in (5) and (6) may be summarized in several ways such as using the mode to estimate the respective parameters. Here the means are utilized.

$$E(\lambda|X) = \frac{X+v}{A+a} \frac{F(X+v+1,\beta;\ X+\alpha+\beta;\ A/(A+a))}{F(X+v,\beta;\ X+\alpha+\beta;A/(A+a))} \tag{7}$$

$$E(p|X) = \frac{X + \alpha}{X + \alpha + \beta} \; \frac{F(X + v, \beta;\, X + \alpha + \beta + 1;\, A/(A + a))}{F(X + v, \beta;\, X + \alpha + \beta; A/(A + a))} \tag{8}$$

The standard deviation offers one measure of variation and is given by

$$\sigma(\theta|X) = [E(\theta^2|X) - E^2(\theta|X)]^{1/2} \tag{9}$$

where θ represents p and λ. The second moments are

$$E[p^2|X] = \frac{(X+\alpha)(X+\alpha+1)}{(X+\alpha+\beta)(X+\alpha+\beta+1)} \; \frac{F(X+\nu, X+\alpha+2; X+\alpha+\beta+2; -A/a)}{F(X+\nu, X+\alpha; X+\alpha+\beta; -A/a)} \tag{10}$$

and

$$E[\lambda^2|X] = \frac{(X+\nu)(X+\nu+1)}{(A+a)^2} \; \frac{F(X+\nu+2, X+\alpha; X+\alpha+\beta; A/(A+a))}{F(X+\nu, X+\alpha; X+\alpha+\beta; A/(A+a))} \tag{11}$$

Further properties of densities (5) and (6) are discussed in Kutran (1975) along with interesting related distributions.

A Gallinule Example

Gallinules (*Porphyrula martinica* and *Gallingula chloropus*) nest in clumps of emergent vegetation on the edges of canals in the Lacassine Wildlife Refuge. Using an airboat we made a cursory search of 500 linear feet or 0.5 (1000 feet) and found four nests. An exhaustive search of the same region revealed that seven nests had been overlooked in the cursory search. In the absence of other prior information we set $\alpha = 5$, $\beta = 8$, $v = 12$, and $a = 0.5$ feet. Then we made a cursory search of an additional $A = 4.3(1000)$ linear feet and discovered $X = 21$ gallinules. With the assumptions outlined above, (λ|X) is estimated by (7)

$$E[\lambda^2|X] = \left(\frac{33}{4.8}\right) \frac{F(34,8;34;4.3/4.8)}{F(33,8;34;4.3/4.8)} = 16.05.$$

That is, we estimate 16.05 nests per 1000 linear feet. The fact that this estimate is based on little information is reflected in the fact that the *a posteriori* standard error $\sigma(\lambda|X) = 4.67$ is about 20% of the mean. Similarly, the estimate $E(p|X) = 0.36$ is hedged by a standard error $\sigma(p|X)$ which is some 40% of $E(p|X)$. The *a posteriori* distribution of λ and p is thus rather diffuse, as it should be. This exercise can be compared with a similar study, unfortunately not concerned with gallinule nests, where more data were collected.

A BICYCLE EXAMPLE

An attempt was made to estimate λ, the average number of (parked) bicycles per house in a certain area of Lafayette, Louisiana, and p, the probability that a bicycle in this area is invisible from the street.

The "training sample" consisted of three streets (53 houses) on which a door-to-door census was made to determine the exact number (94) of bicycles. In a subsample (2 streets), a cursory visual search was also made and 35 bicycles were sighted while 19 bicycles were present, as ascertained by the door-to-door survey, but not sighted.

We considered that our model fit at least crudely and set $a = 53$ (houses), $v = 94$, $\alpha = 36$, and $\beta = 20$. Then 5 more streets ($A = 119$ houses) were subjected to cursory search. On the basis of the data from the training sample, one would predict that $E(X) = 137$ bicycles, more or less, would be sighted in this main sample area. As it happened, the number $X = 107$ turned out to be about 1.5 standard deviations below the expectation. Hence, the new data had a considerable impact on our estimation of λ. For example, the posterior mean value of λ, namely $E(\lambda|X) = 1.64$ bicycles per house, was smaller than the prior mean $E(\lambda) = 1.77$. Similarly, the estimate of visibility p was lowered from $E(p) = 0.64$ to $E(p|X) = 0.59$.

Reflecting the greater amount of information on bicycles as opposed to gallinule nests, the *a posteriori* coefficient of variation of λ was only $\sigma(\lambda|X)/E(\lambda|X) = 11\%$. The most striking difference between this example and the other is that here we have much less uncertainty, either before or after the main sampling effort, about the value of p. In fact $\sigma(p)$ is only 0.02 and $\sigma(p|X)$ is down to 0.003.

CONCLUSIONS

It seems, on the basis of the examples we have considered, that our formally Bayesian approach to the analysis of data on density and visibility can give very sensible and appropriately hedged estimates, but we think that the conclusions should be analyzed cautiously. In fact, the Bayesian data analysis seems to have some built-in warning signs. For instance, in the bicycle example, the *a posteriori* correlation between λ and p was about 35%, a value which expresses in a very precise sense the lack of independence between our information about density and visibility.

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GROWTH OF YARROW'S SPINY LIZARD, *SCELOPORUS JARROVI* (PHRYNOSOMATIDAE)

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Abstract.—Growth of *Sceloporus jarrovi* was estimated using regression analysis of size frequency changes from large samples. Mean SVL of neonates was 28 ± 0.99 mm (range 26-30 mm); mean weight at birth was 0.80 ± 0.07 g (range 0.62-1.02 g). Larger females had larger litters and gave birth to neonates of greater birth weight than did smaller females. On average, young-of-the-year experienced an increase in SVL of 32 mm and an increase in weight of 7.2 g to reach a SVL of 60 mm and a weight of 8 g by their first aggregation period. At all ages, males grew faster than females. Maximum size recorded for males was 99 mm SVL, 35.3 g as compared to 97 mm SVL, 34.4 g for the largest female. *Key words*: *Sceloporus jarrovi*; lizard; growth; Arizona.

Sceloporus jarrovi Cope 1875 is a medium-sized sceloporine lizard with adult males reaching 105 millimeters (mm) maximum snout-vent length (SVL) and with an expected life span of approximately eight years (Ruby and Dunham, 1984). Individuals are found on rocky outcrops in woodlands at elevations of 1370-3350 meters (m) from southeastern Arizona and southwestern New Mexico to Hidalgo, Mexico (Stebbins, 1985). *Sceloporus jarrovi* can mature at five months of age at low elevations and at 15 months of age at high elevations (Ballinger, 1973, 1979). Breeding occurs in September and October; ovulation occurs in November and a single litter is born the following June (Goldberg, 1971). There is a summer activity period and a winter aggregation period (Ruby, 1977), but the lizards remain active throughout the winter aggregation period and feed (Goldberg and Bursey, 1990a).

Sceloporus jarrovi has been the subject of numerous studies. Data on the reproductive cycle have been provided by Goldberg (1970a, 1971) and Ballinger (1973). Energetics have been discussed by Congdon et al. (1979, 1982) and Tinkle and Hadley (1973, 1975); fat and liver cycles by Goldberg (1972). Ecology has been studied by Ballinger (1973, 1979), Simon (1975) and Simon and Middendorf (1976) and life history by Ruby and Dunham (1984). Aspects of behavior have been examined by Ruby (1977, 1978, 1981) and food intake by Goldberg and Bursey (1990a). Research on parasites has been reported by Telford (1970), Mahrt (1987, 1989), Goldberg and Bursey (1990b, 1992), and Bursey and Goldberg (1991, 1992). The purpose of this study was to estimate growth for individuals from a low-elevation population of *S. jarrovi*.

MATERIALS AND METHODS

There are two basic methods that may be used to determine growth within a population (Zweifel and Lowe, 1966). One method involves collecting a large sample over a period of time in which size classes may be seen to progress through the sample. The second method is to measure, mark, release, and recapture individuals from the population. This study utilizes the former method.

From January 14, 1967 through December 11, 1969, 922 *S. jarrovi* were collected by hand-held noose at Kitt Peak (31° 95′N, 111°59′W) in the Baboquivari Mountains, Pima County, Arizona at elevations between 1730 and 1884 m. The lizards were taken to a laboratory at the University of Arizona (Tucson) and within two hours of capture measured to the nearest 1.0 mm and weighed to the nearest 1.00 gram (g) (Mettler P 120 balance). Forty-four of the lizards were gravid and were maintained in the laboratory through parturition; they delivered 281 young (see Goldberg, 1970b for maintenance details). Weight, SVL and day of capture or day of birth were recorded for each individual. All lizards except the 44 gravid individuals and their offspring were then sacrificed and utilized in a study of the ovarian and fat cycles (Goldberg, 1970a, 1971, 1972). The carcasses were later preserved in 10% formalin and deposited in the Whittier College (California), Department of Biology Museum.

Since lizards were collected over a 1077 day period, presentation of the entire data set is standardized to the first day of collection; i.e., January 14, 1967 is taken as Day 1. When annual activity/aggregation periods are pooled, the data are standardized to the assigned calendar date for the beginning of that period; i.e., in Arizona, the activity season for the low-elevation Kitt Peak population of *S. jarrovi* begins in March and extends through November (assigned calendar dates, March 1-November 30). The lizards are in winter aggregation sites, typically rock outcrops, from December through February (assigned calendar dates, December 1-February 28). The data result from removal sampling with each individual sampled only once. Data were analysed and graphs produced on a Macintosh SE/30 using Statview SE + Graphics™.

RESULTS AND DISCUSSION

SVL and weight data for the 1203 individuals in the sample from the low-elevation Kitt Peak population are shown in Figs. 1 and 2, respectively. Three birthing periods are present, June, 1967, 1968, 1969. Neonates and young-of-the-year are readily recognized by SVL and weight. These low SVL's and weights rapidly disappear from the collections. Unfortunately, size classes of adults (1-8 year) are not readily apparent from Figs. 1 and 2.

Birth SVL and weight were obtained from 281 young of the 44 gravid lizards maintained in the laboratory. Minimum SVL of captive gravid lizards was 62 mm, maximum SVL was 88, mean 76.2 mm. There was no significant difference in SVL for 1967, 1968 and 1969 gravid lizards (Kruskal-Wallis statistic = 5.11, 2 df, $P > 0.05$) or in litter size (Kruskal-Wallis statistic = 2.55, 2 df, $P > 0.05$) although the smaller females in each subsample had smaller litter sizes than did the larger lizards (Fig. 3). Litter size increased by approximately one embryo per 3 mm SVL; mean litter size was 6.4. Within the Kitt Peak sample, all births during any year were within a three week period in the month of June, earliest births were June 3, 1967; latest births June

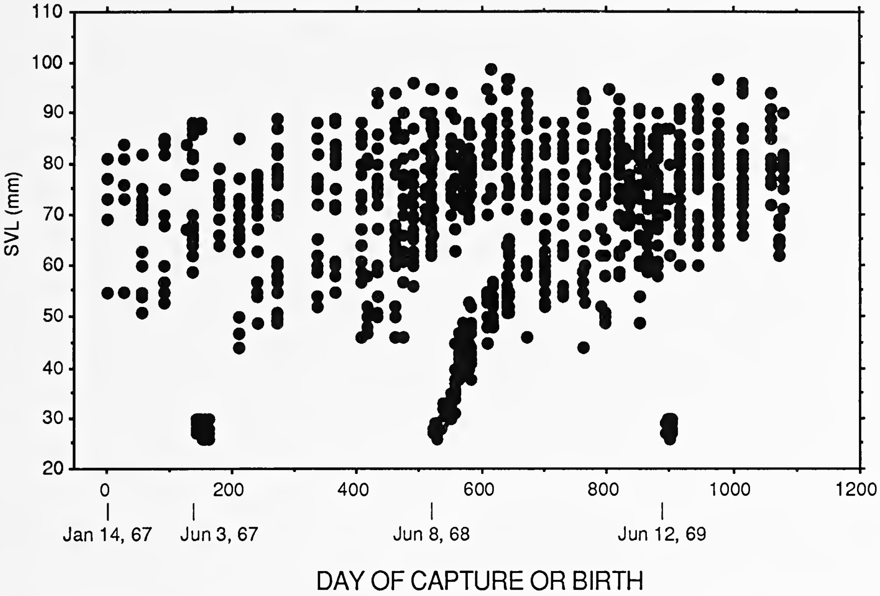

FIGURE 1. SVL data for the sample of the Kitt Peak population (N = 1203) of *Sceloporus jarrovi* collected January 14, 1967 through December 11, 1969. Each dot represents one individual.

30, 1969. Mean SVL of neonates was 28 ± 0.99 mm (range 26-30 mm); mean weight was 0.80 ± 0.07 g (range 0.62-1.02 g). There was no significant difference in SVL of neonates from the 10 smallest (62-67 mm) gravid lizards and the 10 largest (84-88 mm) gravid lizards (N = 32, 86, respectively; mean 28.0 mm, 27.9 mm, respectively; Kruskal-Wallis statistic = 3.41, 1 df, $P > 0.05$). However, there was marginally significant difference in weight of neonates from these lizards (mean 0.77 g, 0.81 g, respectively, Kruskal-Wallis statistic = 3.86, 1 df, ($P < 0.05$). Thus, larger lizards gave birth to neonates with greater birth weights. Sex ratios in these 20 litters were not significantly different from the expected 1:1 ratio (61 males, 69 females); but there was significant deviation from a 1:1 ratio between the 10 smallest and 10 largest gravid lizards $X^2 = 3.98$, ldf, $P < 0.05$). Sex ratio of neonates from the 10 smallest gravid lizards was 1.5 males to 1 female; from the 10 largest gravid lizards was 0.7 males to 1 female. Ballinger (1973) found similar patterns for litter sizes in high-elevation populations of *S. jarrovi* and *S. poinsettii* where the lizards increased approximately one embryo per 3 mm SVL, although he found no significant difference between weights of embryos produced by yearling and adult *S. jarrovi*. Ballinger (1973) also reported significant deviations from a 1:1 sex ratio for yearlings.

Rate of growth for young-of-the-year was estimated from 124

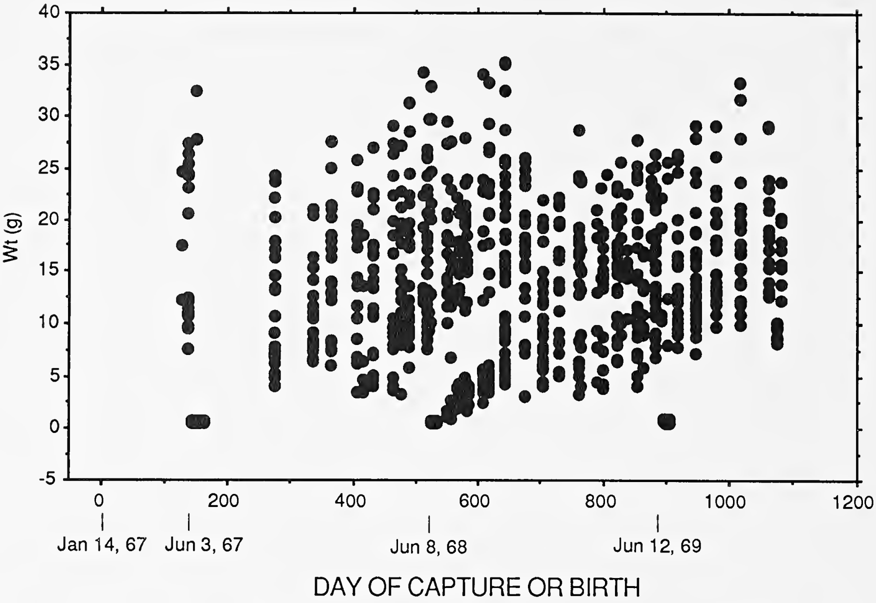

FIGURE 2. Weight (g) data for the sample of the Kitt Peak population (N= 1112) of *Sceloporus jarrovi* collected January 14, 1967 through December 11, 1969. Each dot represents one individual.

individuals (52 females, 72 males) captured between June 8 and November 10, 1968. These data points are in Figs. 1 and 2. The smallest individual in this subsample was a female of 28 mm SVL weighing 0.81 g; the largest individual was a male of 69 SVL weighing 10.69 g. Growth rates for males and females were analysed separately. Regression analysis indicated a mean increase in length of 34 mm for females ($y=20.602 + .406x - .001x^2$; $r^2=.9$) and 37 mm from males ($y = 18.598 + .506x - .001x^2$; $r^2=.9$) over the 165 days between birth and the beginning of the aggregation period or a daily mean increase in length of 0.206 mm for females and 0.224 mm for males. Comparison of the two regression lines (Neter and Wasserman, 1974) for male and female SVL revealed a significant difference, F = 19.5 (2,120 df, $P < 0.001$). Regression analysis indicated a mean increase in weight of 7.57 g for females ($y=0.041x + 0.011$; $r^2 = 0.8$) and 9.69 for males ($y=0.1x-0.9$; $r^2=0.8$) for this same time period or a daily mean increase of 0.046 g for females and 0.059 g for males. Comparison of the two regression lines for male and female weights revealed a significant difference, F = 17.85 (2,106 df, $P < 0.001$). Yearling males increased in SVL and weight more rapidly than females and entered the first aggregation period significantly larger than females.

Rate of growth of adult *S. jarrovi* during the summer activity season was estimated from 618 individuals (389 females, 229 males) captured

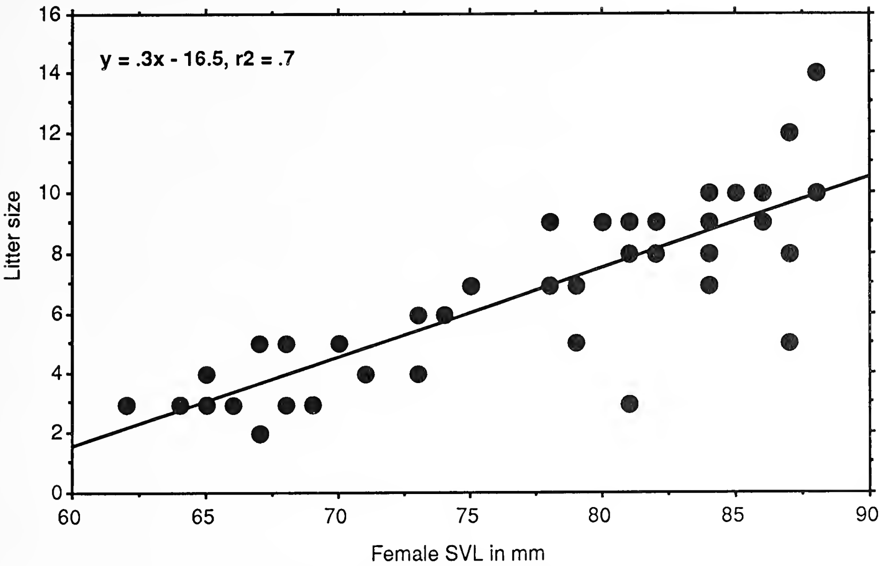

FIGURE 3. Regression of litter size on SVL for 44 gravid *Sceloporus jarrovi* maintained in the laboratory.

March-October 1967, 1968 and 1969. Young-of-the-year were excluded from this subsample. The smallest individual in this subsample was a male of 46 mm SVL (captured April, 1968); it also had the least weight, 3.32 g. The individual of greatest SVL was a male of 99 mm (weight = 33.32g); the individual of greatest weight was a male of 35.51g (SVL = 97 mm). Regression analysis indicated a mean increase of 8.5 mm in SVL for females ($y = .030x = 70.5$; $r^2 = 0.1$) and 11.7 mm for males ($y - 0.046x = 73.4$; $r^2 = 0.1$) over the 275 day activity period or a mean increase of 0.031 mm for females and 0.042 mm for males per day. Comparison of the two regression lines for male and female SVL revealed a significant difference, $F = 21.97$ (2,614 df, $P<0.001$). Regression analysis indicated a mean increase in weight of 2.8 g for females ($y = 0.0099x + 14.6$; $r^2 = 0.014$) and 9.6 g for males ($y = 0.036x + 13.4$; $r^2 = 0.2$) over the 275 day activity period or a mean increase of 0.010 g for females and 0.034 g for males per day. Female weights may be skewed, since during the first 105 days of the activity period, females are carrying developing embryos. Regardless, males grew faster than females. The r^2 values are low because the data may represent as many as 7 year classes.

Rate of growth of adult *S. jarrovi* during the winter aggregation period was estimated from 167 individuals (88 females, 79 males) captured December-February 1967, 1968 and 1969. The smallest individual in this subsample was a 44 mm SVL female that also had the least weight, 3.28 g. The largest individual in this subsample was a

94 mm SVL male that also had the greatest weight, 28.93 g. Regression analysis indicated a mean increase of 0.2 mm for females ($y = 0.0013x + 70.8$; $r^2 = 0.000012$) and 4.0 mm for males ($y = 0.045x + 71$; $r^2 = 0.0083$) in SVL over the 90 day aggregation period or a daily mean increase of 0.002 mm for females and 0.044 mm for males. Comparison of the two regression lines for male and female SVL revealed a significant difference, $F = 27.03$ (2,163 df, $P < 0.001$). Regression analysis indicated a mean increase of 0.9 g for females ($y = 0.0083x = 12.6$; $r^2 = 0.0023$) and 3.4 g for males ($y = 0.035x = 12.6$; $r^2 = 0.019$) over the 90 day aggregation period or a daily mean increase of 0.010 g for females and 0.037 g for males. Comparison of the two regression lines for male and female weights revealed no significant difference, $F = 0.82$ (2, 152 df, $P > 0.05$). The lack of significant difference between weight regression lines may be due to wide scatter as indicated by the extremely low r^2 values. These data may represent lizards from one to eight years of age.

Shine and Charnov (1992) published data on female age and SVL at maturity for 16 species of snakes and 19 species of lizards. The von Bertalanffy equation was used to characterize asymmptotic growth in length for these species. Body weight has usually been found to be a power function of length with the exponent approximately 3.0. Shine and Charnov (1992) suggest 0.65 year as a mean age and 73 mm SVL for female *S. jarrovi* at maturity; females may eventually reach a maximum size of 90 mm. Females of the Kitt Peak low-elevation population apparently mature at about 0.42 years of age and 60 mm SVL and are capable of reaching 95 mm SVL. An SVL of 60 mm would represent 63% of total expected length for females.

The greatest rate of growth, measured as increase in length or weight, for *S. jarrovi* occurred during the first summer after birth. Neonates which had a mean SVL of 28 mm had increased on average 2.25 times by the beginning of their first aggregation period; weight underwent an average eight fold increase. However, growth, as measured by increases in SVL or weight, was quite variable for individuals. Figure 2 suggests that growth for young-of-the-year may be so slow as to allow only a doubling of SVL or so rapid as to triple SVL. Whether these patterns are genetic or environmental are unknown.

Males grew faster than females at all ages. Adult males apparently grow at relatively constant rates throughout the year (on average, 0.042 mm and 0.035 g per day is suggested by regression analysis, but increase in length follows the von Bertalanffy equation). Females exhibit an intermittent lengthening pattern (on average, 0.031 mm summer; 0.002 mm winter), but a constant increase in weight (0.010 g per day). Such growth patterns could produce males of maximum size in four years and females in six years.

The variation in individual growth rate may be responsible for the maturation patterns reported by Ballinger (1973), in which approximately 60% of the female yearlings matured and mated at an age of four to five months while the remaining 40% did so at an age of 16-17 months. Ballinger (1973) used recapture techniques to study a high-elevation population of *S. jarrovi* from Portal in the Chiricahua Mountains, Cochise County, Arizona during the months of June, July and August. He reported that SVL growth was most rapid in young-of-the-year and that growth rate slowed during each subsequent activity period. Slowed growth of neonates prior to overwintering followed by rapid growth for juveniles and decreasing growth rate for adults have been reported for *Sceloporus occidentalis* and *Uta stansburiana* by Tanner and Hopkins (1972) and *Xantusia riversiana* by Fellers and Drost (1991).

Congdon et al. (1979) measured energetics, temperature and water relations in aggregated *S. jarrovi* and concluded that the total amount of fat in a lizard entering aggregation would satisfy no more than 50% of its winter energy requirement. Goldberg and Bursey (1990a) estimated winter food intake to be approximately one-fifth that of summer food intake. Although it has been shown that *S. jarrovi* depletes fat stores during the aggregation period (Goldberg, 1972), it appears that muscle loss is not a problem. Winter food intake and lessened physical activity may conserve sufficient energy to allow continued growth during the aggregation period.

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ENVIRONMENTAL CORRELATES TO TERRESTRIAL REPTILIAN DISTRIBUTIONS IN TEXAS

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Abstract.—The ability of physiographic and climatological variables to explain variation in terrestrial reptilian distributions in Texas was explored using principal components analysis and discriminant analysis. Variables related to precipitation were major predictors of east-west changes in cluster affinities. North-south changes in cluster affinities were best predicted by variables related to temperature. The degree to which variation in environmental factors predicts cluster affiliations was cited as support of the existence of discrete, biologically significant regions defined by the distributions of the herpetofauna of Texas. *Key words*: distribution; Reptilia; Texas; multivariate analysis.

Recent studies of the distribution of the herpetofauna of Texas have differed in their choice of multivariate statistical techniques and in their interpretation of the results of those analyses. Owen and Dixon (1989) evaluated the patterns of reptile and amphibian distributions in Texas, and found the relationship between the regions defined by cluster analysis to be complex and essentially continuous. Ward et al. (1990) used cluster analysis and detrended reciprocal averaging (DRA) to examine the distributional data for terrestrial reptiles and found discrete faunal regions with complex zones of transition between the regions (Fig. 1). These regions corresponded well to the biotic provinces proposed by Blair (1950) in a subjective analysis of the terrestrial, non-avian vertebrate fauna of Texas.

If the regions identified by Blair (1950) and Ward et al. (1990) are valid reflections of the distributional patterns of the terrestrial reptilian fauna of Texas, then the next question which should be addressed is which, if any, of the quantifiable environmental variables explain the patterns observed in the faunal distributions. The present study explores the relationship between the discrete biogeographic units described by Ward et al. (1990) and a suite of climatological and physiographic variables. If the biogeographic pattern is explained well by the environmental variables, then support is given to the proposition that the distributional pattern of terrestrial reptiles in Texas is essentially discrete rather than continuous.

Methods

The seven clusters used in this study (Fig. 1) are those generated by Ward et al (1990) using disjoint cluster analysis based on the Euclidian distances computed from the presence-absence data for each of 52 terrestrial reptilian species for the 254 Texas

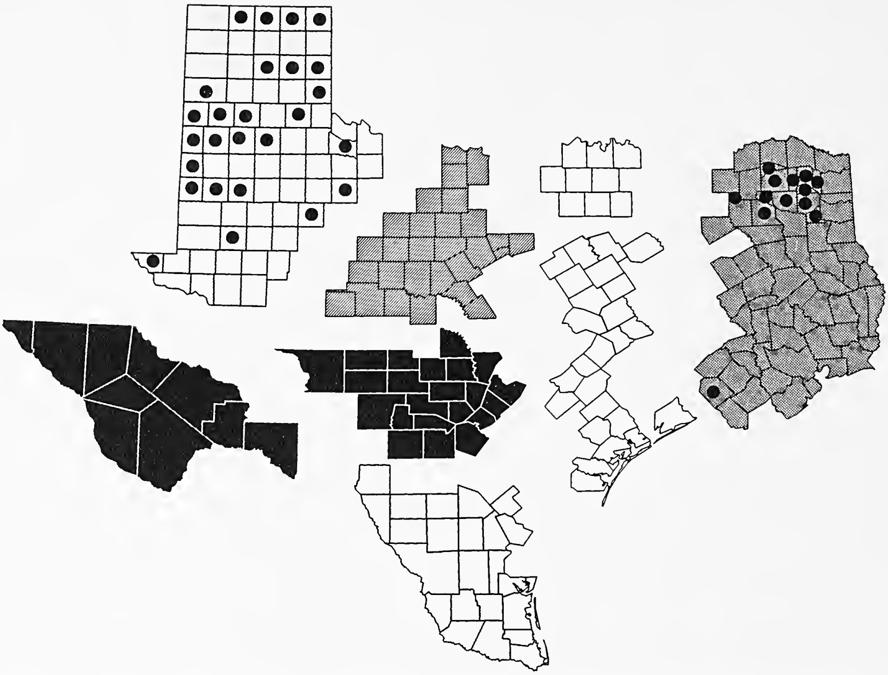

FIGURE 1. Seven faunal regions identified by cluster analysis of presence/absence data of terrestrial reptiles of Texas (Ward et al., 1990). Dots indicate counties not included in the study due to failure to have records for a minimum of 50% of the expected species.

counties. Thirty-nine counties were excluded from the cluster analysis (Fig. 1) because of failure to meet the preset criteria of valid records for at least 50% of the species which would be reasonably expected to occur in a particular county (see Ward et al., 1990, for details of the culling process).

Data on a suite of 22 physiographic and climatological variables were collected from literature sources for each of 215 counties which survived the culling procedure (Ward et al., 1990). A list of these variables, the source from which each variable was obtained, and the abbreviation for each variable for use in subsequent discussion are presented in Table 1. Those variables taken from Owen and Schmidly (1986) were, in the original source, given for a set of quadrats which had been imposed over a map of Texas. For use of these variables in the present study, the data for the quadrat which represented the largest part of each county were assigned to that county.

Due to the many linear dependencies which exist among the environmental variables evaluated in this study, a biased estimation technique was used for combating multicolinearity. Principal Components Analysis (PCA; SAS Institute, 1985) was used to generate a reduced number of orthogonal factors to which a specific amount of variance may be attributed. A factor was retained for further analysis if the eigenvalue for that factor was equal to or greater than 1.0.

Many of the variables included in this study were non-normally distributed. It is possible to criticize the inclusion of such variables in studies employing the general linear model (see Gauch et al., 1977, for a discussion of this criticism in the use of ecological variables). Exploratory analyses, such as PCA, are robust in their ability to identify patterns in complex data sets even if those fail to meet all of the assumptions of the analyses. This is not to minimize the importance of understanding the effect upon

Table 1. Physiographic and climatological variables used in analyses of the relationship between cluster affinities and environmental variability in Texas.

LAT - Latitude to the nearest degree, taken from USGS maps.
LON - Longitude to the nearest degree, taken from USGS maps.
AREA - (Kingston, 1983) County area in square miles.
UALT - (Kingston, 1983) Upper altitude.
RELIF - Relief. UALT - LALT (lower altitude).
MAP - (Kingston, 1983) Mean annual precipitation.
SEAS - (Kingston, 1983) Seasonality of rainfall, calculated as the percentage of MAP falling in that month with the greatest mean rainfall.
SRAIN - (computed from Kingston, 1983) Spring rainfall, computed as mean precipitation falling during the months of March, April, and May.
SURAIN - (computed from Kingston, 1983) Summer rainfall, computed as mean precipitation falling during the months of June, July, and August.
FRAIN - (computed from Kingston, 1983) Fall rainfall, computed as mean precipitation falling during the months of September, October, and November.
WRAIN - (computed from Kingston, 1983) Winter rainfall, computed as mean precipitation falling during the months of December, January, and February.
MINR - (Climatological Data, 1960) Minimum yearly rainfall recorded in the period 1950-1959.
MAXR - (Climatological Data, 1960) Maximum yearly rainfall recorded in the period 1950-1959.
PROD - (Owen and Schmidly, 1986) Net above-ground productivity in g/m per year.
MAT - (Owen and Schmidly, 1986) Mean annual temperature.
GROW - (Kingston, 1983) Growing season (mean number of days per year with temperature above 32°F).
HOTD - (Owen and Schmidly, 1986) Mean number of days per year with an average temperature greater than 89°F.
COLDD - (Owen and Schmidly, 1986) Mean number of days per year with an average temperature less than 33°F.
MAXT - (Owen and Schmidly, 1986) Maximum temperature during period of record.
MINT - (Owen and Schmidly, 1986) Minimum temperature during period of record.
STDH - (Owen and Schmidly, 1986) Standard deviation of mean July temperatures.
STDC - (Owen and Schmidly, 1986) Standard deviation of mean January temperatures.

results and interpretations which failure to meet an assumption may have. But, as Bock et al. (1981) suggested, the evidence for the utility of a multivariate tool is its ability to discover interesting and intelligible patterns among large masses of data. The justification for the use of multivariate analyses with any set of data is the extent to which those analyses are able to discern such patterns. The need to extract as much information as possible from large ecological data sets may be more important than statistical security (Bolter and Meyer, 1986).

To assess the relative contribution of the factors generated by the factor analysis to an explanation of the results of the cluster analysis, a Stepwise Discriminant Analysis (SDA) was performed (SAS Institute, 1985). Cluster designation was used as the class variable.

RESULTS

The PCA of the 22 physiographic and climatological variables for the 215 counties included in the analysis (Table 2) retained four factors. These four factors accounted for a total of 84% of the variance

TABLE 2. Rotated factor pattern generated by a Principal Components Analysis of the physiographic and climatological variables for 215 counties included in an analysis of terrestrial reptilian distributions in Texas.

	FACTOR1	FACTOR2	FACTOR3	FACTOR4
Eigenvalue	10.87	4.45	1.81	1.34
% Variance	0.49	0.20	0.08	0.06
Variable				
MAP	0.96612	0.10478	-0.21096	-0.02142
WRAIN	0.95871	0.14108	-0.10636	-0.06430
MINR	0.92376	0.01860	-0.16108	0.01146
PROD	0.91321	0.16405	-0.22615	-0.03240
SRAIN	0.91182	-0.04665	-0.26789	0.16357
MAXR	0.90225	0.17453	-0.21105	0.01820
FRAIN	0.87314	0.34176	-0.24249	-0.01056
SURAIN	0.80175	-0.02621	-0.17795	-0.24012
SEAS	-0.81895	-0.07959	-0.00120	0.04053
LON	-0.88223	-0.26681	0.30415	-0.06086
MAT	0.17356	0.95932	-0.07302	0.12714
GROW	0.17137	0.89594	-0.09867	-0.01906
MINT	0.10681	0.77607	-0.09737	-0.30578
HOTD	-0.30639	0.72652	0.08021	0.47044
STDH	-0.39658	-0.46295	-0.06408	0.29469
COLDD	-0.33417	-0.89781	0.11487	-0.04260
LAT	0.01267	-0.94828	-0.07839	0.17790
RELIF	-0.28541	-0.12937	0.88916	0.01192
AREA	-0.25737	0.07112	0.86424	0.05509
UALT	-0.57821	-0.46310	0.62658	-0.10083
MAXT	-0.06714	-0.11838	0.04805	0.93275
STDC	0.20914	-0.02064	-0.41311	0.42383

in the data set. The first factor was loaded heavily by all precipitation variables and productivity, and was related strongly to longitude. The second factor loaded heavily by all temperature variables except maximum recorded temperature and variation in winter temperatures, and was strongly associated with latitude. The three physiographic variables (RELIF, AREA, and UALT) loaded heavily on the third factor. The fourth factor was loaded heavily by maximum recorded temperature and moderately by variation in winter temperatures.

The SDA of the ability of the four physiographic/climatological factors to predict the cluster affinities of the 215 counties (Table 3) found that the first three factors explained large amounts of the variation in the data. The first factor, precipitation and productivity, had a significant partial R^2 of 0.85; the second factor, related to temperature, yielded a partial R^2 of 0.68, while the third factor, heavily loaded by physiographic variables, had a partial R^2 of 0.73.

TABLE 3. Summary of the SDA for the ability of the environmental variable factor scores to explain cluster affiliation of the 215 counties included in an analysis of terrestrial reptilian distributions in Texas.

Variable Entered	Order In	Partial R^2	F	Wilks' Lambda
FACTOR1	1	0.848	198.47**	0.15**
FACTOR3	2	0.728	94.47**	0.04**
FACTOR2	3	0.683	75.90**	0.01**
FACTOR4	4	0.062	2.31*	0.01**

*Prob. < .05
**Prob. < .01

DISCUSSION

The results of these analyses demonstrate that the regions discerned in the distribution of terrestrial reptiles in Texas by Ward et al. (1990) are adequately explained by variation in environmental variables. East-west variation in terrestrial reptilian cluster affinity is strongly related to variables associated with precipitation, while temperature variables explain the greatest amount of north-south variation. The strong explanatory power of the first three factors suggests that the determination of distribution, in the terrestrial reptiles, is accomplished via a complex set of phenomena. Precipitation, temperature, and physiographic variables play important roles in determining which set of species occurs in a particular region of the state. The determination of which of the classes of environmental variables is most important for any particular taxonomic grouping of the terrestrial reptiles awaits specific analyses of that group.

Owen and Dixon (1989) found that for the snakes and lizards the environmental variable which correlated most highly with the Detrended Correspondence Analysis (DCA) first axis was mean annual precipitation (MAP). The second DCA axis was most strongly correlated with temperature variables, especially mean annual temperature (MAT), and was interpreted as "a north-south gradient of decreasing mean annual temperature, increasing rigor of winter cold and increasing seasonality of temperature" (Owen and Dixon, 1989, p. 168).

The strong influence of precipitation and temperature found in the present study is in accord with the findings of Owen and Dixon (1989) who, however, used DCA axis position instead of cluster affinity in their analysis. This choice resulted from their decision to interpret the distribution of reptiles in Texas as essentially continuous and clinal. This interpretation differed from that which we proposed (Ward et al., 1990) in that we found significant regions of faunal homogeneity for terrestrial reptiles. We suggest the findings of the present study are in support of the existence of discrete faunal units in Texas. If the groupings of counties produced by the cluster analysis of the faunal distribution were not biologically valid, one would not expect to find partial R^2s of the magnitude reported in this study. We think the reason that the physiographical and climatological data strongly predict cluster affinity is because the clusters are adequate representations of the nature of the distribution of the terrestrial reptiles of Texas.

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LIFE HISTORY CHARACTERISTICS OF THREE MORPHOTYPES IN THE PARTHENOGENETIC *CNEMIDOPHORUS DIXONI* COMPLEX (SAURIA: TEIIDAE) IN TEXAS AND NEW MEXICO

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ABSTRACT.—We compared life history characteristics of three morphotypes (or pattern classes A-C) of the parthenogenetic lizard, *Cnemidophorus dixoni.* A and B were studied in Trans-Pecos Texas from 1989 through 1993; it was not possible to study C in Hidalgo County, New Mexico. The peak activity period for both *C. dixoni* A and B appeared to be between 1045 and 1245 Central Daylight Time. No significant differences were found in cloacal body temperature between *C. dixoni* A and B; however, mean air temperatures at sites of collection were higher for B than for A. *C. dixoni* C grows to a larger adult body size than either A or B. Populations of A and B contain three age classes; C includes either a fourth age class or has a more rapid growth rate. *C. dixoni* C also has a larger clutch size than A and B. The population of *C. dixoni* in western New Mexico is not a disjunct population of B located some 500 kilometers west of Presidio County, Texas. It is a distinctive form worthy of efforts to insure its survival. *Key words*: *Cnemidophorus dixoni*; parthenogenesis; activity; body temperature; body size; age classes; reproduction.

Zweifel (1965) briefly characterized an unusual population of parthenogenetic whiptail lizards known to occur only in the Antelope Pass area in the Peloncillo Mountains, Hidalgo County, New Mexico. This form was allocated to *Cnemidophorus tesselatus* and informally designated pattern class F, one of six morphotypes recognized by Zweifel (1965). Subsequently, Scudday (1973) noted the presence of two somewhat similar parthenogens in the Chinati Mountains, Presidio County, Texas. Scudday maintained that his newly discovered populations and pattern class F should be allocated to the new species, *Cnemidophorus dixoni.* He identified two color pattern classes of *C. dixoni*; A, a population in Presidio County from which the holotype was designated, and B which included Zweifel's pattern class F in Hidalgo County and the population that differs from A in Presidio County.

Our unpublished analyses of morphological variation identified three morphotypes in *C. dixoni* which we call A and B, in southwestern Texas, and C, found in western New Mexico. We agree with Scudday (1973) on the identity of *C. dixoni* A (lizards with irregular dorsal lines in the Chinati Mountains), but we find that his pattern class B actually includes two distinctive forms. Thus, we allocate lizards with fragmented dorsal lines in the Chinati Mountains to morphotype B, and reallocate lizards with fragmented dorsal lines and distinctive meristic features in the Peloncillo Mountains to morphotype C.

Whether these three morphotypes are best treated as populations without formal taxonomic recognition, separate species, subspecies of *C. dixoni,* or pattern classes of *C. tesselatus* is subject to divergent opinions (Zweifel, 1965; Scudday, 1973; Cole, 1985; Walker, 1986; Frost and Wright, 1989; Densmore et al., 1989; Wright, 1993). It is certain, however, that the three pattern classes of *C. dixoni* are diagnosable entities with different patterns of distribution. Because *C. dixoni* A and B coexist at several sites in Presidio County that were unknown to Scudday (1973), being allopatric at other sites, and both forms are widely disjunctive and morphologically distinct from *C. dixoni* C in Hidalgo County, we analyzed these pattern classes separately. Here, we present life history data for *C. dixoni* A and B, with emphasis on specimens acquired in 1991, 1992, and 1993, and compare these forms with a sample of *C. dixoni* C.

METHODS

We necropsied 233 specimens of *C. dixoni* A, 97 specimens of B, and 27 specimens of C. We were unable to study the Hidalgo County form in the field, which today is variously considered as threatened or endangered. Fortunately, we acquired two live adults of *C. dixoni* C through the New Mexico Department of Game and Fish and we examined preserved specimens in the American Museum of Natural History and University of Colorado Museum. Most specimens of *C. dixoni* A and B were collected from 1988 through 1993 by JEC during over 100 field days between the Rio Grande and parts of San Antonio Canyon in the Chinati Mountains, Presidio County (see Appendix). Specimens of A and B deposited in Sul Ross State University were also examined. Field data included Central Daylight Time (CDT), cloacal body temperature (CBT) taken with a Schultheis quick-reading thermometer, and air temperature (AT) 5-6 centimeters above the capture site. Prior to injection with 10% formalin, fresh body mass (FBM) was determined with a Pesola balance to 0.1 gram (g). The snout vent length of each preserved lizard (PSVL) was also measured to millimeter (mm) after storage in 70% ethanol. Clutch size was based on counts of vitellogenic follicles ($\geq$3.0 mm) and/or oviductal eggs, both measured to the nearest 0.5 mm. Means are reported ± 1 SE.

RESULTS AND DISCUSSION

Daily Activity

Based on 1989 and 1990 data, we suggested that the peak activity period for *C. dixoni* in Presidio County occurred between 1045 and 1245 (Walker et al., 1991). Addition of the May-June 1991, May-July 1992, and June-July 1993 time records to the data base for *C. dixoni* did not alter our basic conclusion about the peak activity period. Comparison of activity data for *C. dixoni* A and B with data presented by Schall (1993; Fig. 2) for other species of *Cnemidophorus* in Trans-Pecos Texas indicates that both forms resemble gonochoristic *C. marmoratus* (=*C. tigris*) more closely than parthenogenetic *C. tesselatus* in the length of the daily activity period (for discussion of evolutionary relationships see Parker and Selander, 1976; Densmore et al., 1989).

Collection times were grouped by 15 minute intervals for University of Arkansas specimens of *C. dixoni* A (N=204) and B (N=72). For A, 29.4% were observed between 1045 and 1245 and 21.4% between 1245 and 1445; activity decreased between 1445 and 1645 (14.1%) and a second peak occurred between 1645 and 1845 (23.9%). Only 10.1% of all *C. dixoni* A were found after 1845. For B, collection time data were biased toward the afternoon (19.4% before 1445 and 80.5% after 1445). We predict that a larger sample of B would be found to have a bimodal pattern of daily activity similar to that of A.

Cloacal Body Temperature and Air Temperature

C. dixoni is similar to other species of *Cnemidophorus* in having an unusually high mean CB temperature compared with many saurians in other families (see summary of papers in Schall, 1976 [Table 15]; Walker et al., 1991). Addition of 1991 and 1992 temperatures (none taken in 1993) to the 1989-1990 data for *C. dixoni* permitted us to compare CBT and AT data for A and B. We found no significant differences (Duncan's Multiple Range Tests; P of $\alpha = 0.05$) in mean CBT either between A (39.71 ± 0.13, 34.0-43.2, N=157) and B (40.20 ± 0.22, 35.0-44.3, N=53) or among samples representing each population. However, the mean AT for the pooled sample of A (35.27 ± 0.31, 25.1-44.2, N=155) is significantly lower than the mean AT for the pooled sample of B (37.81 ± 0.62, 26.0-46.0, N=53); this AT pattern also holds for individuals of A and B collected after 1445 (when most specimens of B were collected). The higher mean AT observed for *C. dixoni* B reflects its utilization of more typically desert habitats with creosote where it is more often sympatric with *C. marmoratus* than is true of *C. dixoni* A.

Body Length and Body Mass

A total of 184 adult *C. dixoni* A collected between 1989 and 1993 averaged 80.89 ± 0.47 (67-96) mm PSVL (Fig. 1); 166 of these averaged 16.21 ± 0.32 (8.2-30.3) g FBM. A total of 66 adult *C. dixoni* B averaged 78.74 ± 0.94 (65-98) mm PSVL (Fig. 1); 63 of these averaged 14.77 ± 0.51 (7.5-25.5) g FBM. A total of 25 sexually mature *C. dixoni* C averaged 90.4 (78-103) mm PSVL.

Although the PSVL and FBM means for *C. dixoni* A are significantly larger than for B, the differences are not great and it may

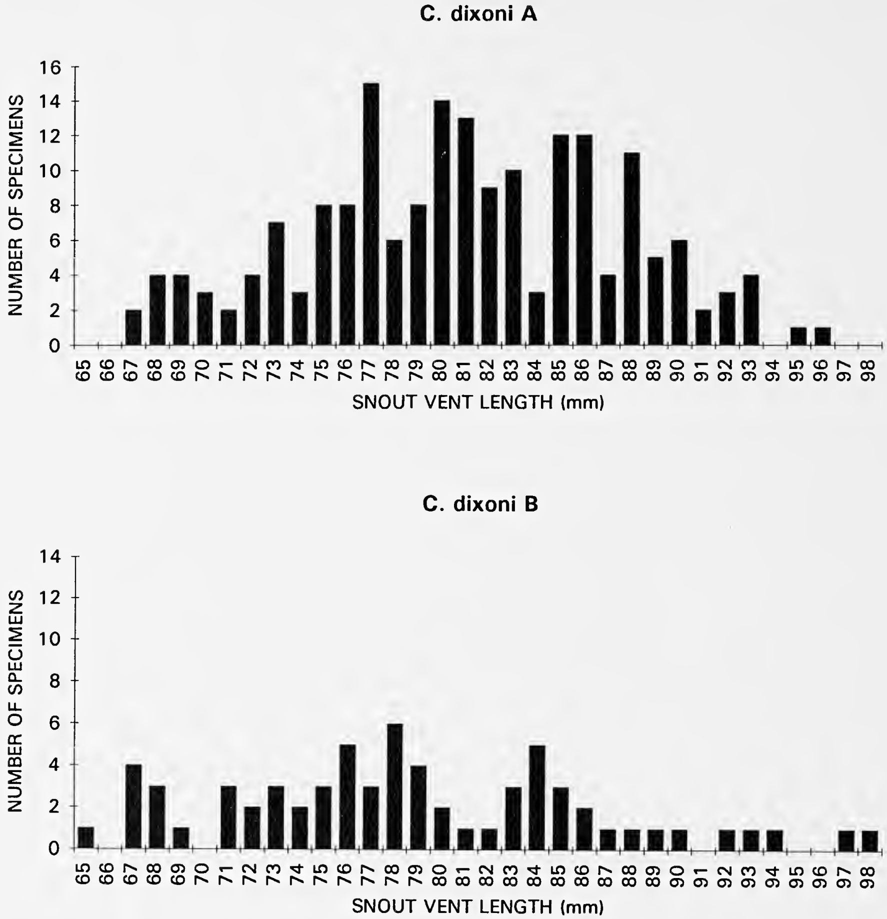

FIGURE 1. Histograms showing the snout vent length of each preserved specimen of adult parthenogenetic *Cnemidophorus dixoni* A and B collected in Presidio County, Texas, from 1989 through 1993.

be that additional specimens of B would show that it has the same average body size as A. We base this on the observation that both morphotypes have a maximum PSVL of 96-98 mm and a maximum FBM of 30-31 g (based on the actual FBM of the largest *C. dixoni* A and log regression estimate of the FBM of the largest B). One gravid female A, collected 1 June 1991, increased the known FBM for this pattern class by 19.8% from 24.3 g (Walker et al., 1991) to 30.3 g. Although individuals of *C. dixoni* A (8.69%) and B (9.09%) only rarely attain a body size in excess of 89 mm PSVL in Presidio County, lizards over 89 mm PSVL make up 51.8% of the sample of *C. dixoni* C from Hidalgo County. Eleven of these individuals range between 94 and 103 mm PSVL; however, only two *C. dixoni* A and three B exceed 93 mm PSVL.

Age Classes

To investigate age class structure we separately analyzed PSVL data for *C. dixoni* A and B, adding data for lizards obtained in 1991, 1992, and 1993 to the 1989-1990 data base utilized by Walker et al. (1991). Data for each form were separately arrayed in 5 mm intervals between 38 and 98 mm and analyzed by using probability graph paper (Harding, 1949). The analysis of the large sample of *C. dixoni* A clearly indicated trimodality in the PSVL distributions. Though somewhat less apparent, similar, if not identical, trimodality is also apparent in the analysis of the smaller sample of *C. dixoni* B. Lizards of the following size classes formed the three modal distributions: 38-55 mm, 56-75 mm, and 76-100 mm. These separate distributional patterns of PSVL data for *C. dixoni* A and B are in agreement with the length frequencies reported by Walker et al. (1991) for a pooled sample of the two forms. This analysis was not possible in the small sample of C; however, we predict that it differs from A and B in one or two attributes. The large number of individuals between 94 and 103 mm PSVL is either indicative of a fourth age class in the Hidalgo County population or a much more rapid growth rate than in A and B.

Reproductive Characteristics

Average clutch size for 148 *C. dixoni* A was 2.93 ± 0.07; average clutch size for 52 B was 2.90 ± 0.14. Mean clutch sizes for the 1991 (3.11 ± 0.17), 1992 (2.84 ± 0.17), and 1993 (2.80 ± 0.17) samples of *C. dixoni* A varied little and were similar to data reported for this form by Walker et al. (1991); however, mean clutch size for the 1993 (3.40 ± 0.30) sample of B was significantly higher than for the 1993 sample of A. These data increase the known clutch size for both A and B to six. Twelve gravid *C. dixoni* C had an average clutch size of 4.66 ± 0.72 and maximum clutch size of eight. Clutch size is correlated with PSVL in each of the three pattern classes.

Separate analyses of vitellogenic follicles in left and right ovaries and oviductal eggs in left and right oviducts revealed larger numbers of ova on the right side of the body in *C. dixoni* A, B, and C. This could reflect an accomodation for the stomach, which may fill the left posterior quadrant of the coelom when engorged; however, there were no significant bilateral differences in egg number in either A or B lizards with four to six eggs and in C lizards with five to eight eggs. Average oviductal egg dimensions in three *C. dixoni* C are: 8.5 x 15.0 mm (N=7), 8.5 x 16.0 mm (N=8), and 9.5 x 18.5 mm (N=4) (for egg measurements in A and B see Walker et al., 1991).

CONCLUSIONS

Subsequent to their formation, whether or not by separate hybrid origins, *C. dixoni* A and B have diverged little, if at all, in body size, mean body temperature, average and maximum clutch size, egg size, and timing of reproductive cycles. Both have distinctively different color patterns throughout life and all specimens examined by us (see Appendix) could be unambiguously allocated to one pattern class or the other. Moreover, each form has developed a distinctive pattern of distribution, albeit in the geographically restricted Chinati Mountain region. In our study area, *C. dixoni* A is often found in sympatry with *C. gularis septemvittatus* (apparent paternal progenitor) in transition areas with montane slopes, whereas B is usually found in sympatry with *C. marmoratus* (apparent maternal progenitor) in transition areas with desert flats. A few sites are also known where A and B coexist with each other and both of their progenitors.

C. dixoni C in Hidalgo County can no longer be regarded as a disjunct population of *C. dixoni* B located some 500 kilometers west of Presidio County. This form is not only distinct from A and B in meristic characters and color pattern, it also has a larger maximum and average body size than either of these forms. Correlated with this larger body size is a larger clutch size. At present, it is not clear whether these differences reflect a separate origin for C or whether they are evidence of postformational divergence. Given the small geographic area inhabited by *C. dixoni* C in New Mexico, it is clear that the profound management considerations arising from this study recommend the taking of appropriate measures to ensure the survival of this distinctive form.

Acknowledgments

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APPENDIX

Museum numbers for specimens deposited in collections: AMNH, American Museum of Natural History; SRSU, Sul Ross State University; UADZ, University of Arkansas Department of Zoology; UCM, University of Colorado Museum.

Specimens of *C. dixoni* A.examined from Presidio County, Texas: UADZ 3553, 3557-3558, 3560-3563, 3566-3567, 3570, 3609-3610, 3612-3617, 3626-3630, 3648-3652, 3660-3669, 3675-3677, 3679-3680, 3688, 3696, 3704, 3756-3758, 3761, 3766, 3767-3768, 3770, 3779, 3782-3790, 3820, 3842-3843, 3852-3853, 3856, 3866-3868, 3870-3872, 3882-3884, 3887-3892, 3897, 3901-3905, 3944-3945, 3954, 3957, 3961-3964, 3972-3973, 3977-3980, 3983-3984, 4001, 4005, 4011, 4014-4015, 4026, 4030, 4032-4033, 4347-4348, 4352, 4354, 4360, 4366-4368, 4374-4377, 4382, 4384, 4387-4392, 4397, 4399, 4400-4401, 4404-4405, 4407-4409, 4411-4412, 4419, 4427, 4429-4430, 4436-4437, 4439, 4572-4574, 4580, 4602, 4614-4616, 4626, 4629, 4632, 4634, 4636, 4642, 4645, 4689, 4691-4692, 4695-4696, 4707, 4714, 4721, 4737, 4739, 4741, 4744, 4753, 4758, 4765, 4772, 4775, 4922, 4930, 4943, 4948-4949, 4952-4953, 4957, 4963, 4965, 4967, 4970, 4972, 4975, 4982, 5052, 5061-5062, 5065, 5106, 5124-5125, 5127, 5134; SRSU 1216, 1443-1444, 4368, 4384-4387, 4393, 4407, 4424-4427, 4446, 4448, 4558, 4563, 4566-4567, 4769, 4821-4822.

Specimens of *C. dixoni* B examined from Presidio County, Texas: UADZ 3457-3458, 3461-3462, 3463-3465, 3469, 3473-3474, 3568, 3571, 3602, 3678, 3695, 3697-3698, 3700, 3759, 3769, 3819, 3854, 3869, 3885-3886, 3943, 3955-3956, 3958, 3970-3971, 3985, 4016-4017, 4027, 4031, 4034, 4349-4350, 4359, 4383, 4385, 4417-4418, 4426, 4428, 4607, 4641, 4723-4726, 4733-4736, 4740, 4742, 4750, 4754-4755, 4759-4762, 4764, 4767, 4934, 4936, 4946, 4969, 4973-4974, 4976, 5054, 5056-5057, 5063-5064, 5066-5068, 5117; SRSU 883, 885, 892, 911-912, 1000, 1183, 1296, 3029, 4443, 4555, 4803, 5809, 6040.

Specimens of *C. dixoni* C examined from Hidalgo County, New Mexico: UADZ 3551-3552, AMNH 73739, 80680-80691, 84834-84836, 86994-86996; UCM 14666-14668, 17252, 49439-49440.

THE OCCURRENCE OF THE GENUS *BRACHIONUS* DALLAS, 1766 (ROTATORIA), IN NORTHEASTERN TEXAS RESERVOIRS

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Abstract.—An extensive study of the occurrence of rotifers of the genus *Brachionus*, Family Brachionidae, Order Ploima, Class Monogonota was conducted from 1982 to 1987 in seven northeastern Texas reservoirs. Eleven species of *Brachionus* were identified. *Brachionus angularis, B. bidentata, B. havanaensis, B. rubens, B. quadridentatus*, and *B. caudatus* were present during all seasons. *Brachionus calyciflorus* occurred in the spring and autumn. *Brachionus budapestensis* was identified in March and June and from September to November. No patterns could be discerned for *B. urceolaris, B. rubens, B. variabilis*, and *B. zahnisera*. The smallest number of species occurred during the winter in all reservoirs. All reservoirs had nine species of *Brachionus* except Cypress Springs which only had four species. *Key words*: *Brachionus*; Rotifera; Monogonota; rotifers; Texas lakes.

The availability and quality of water for agricultural, industrial, and home consumption are among the most important environmental concerns of the nation, particularly in Texas. Chief indicators of water quality are the populations which the water supports. The maintenance or restoration of the biological integrity of our surface waters is dependent on our understanding of the pollution-caused changes in the taxonomic composition of the community (Stemberg, 1979). Rotifers are the taxonomic group most characteristic of fresh water (Pennak, 1978) and they are a major indicator of water quality. Rotifers are quite sensitive to environmental changes due to their short life cycles. Jennings (1900) stated that species lists of all organisms in a given body of water must be on record so that investigators could know that changes were taking place.

There are few records available concerning rotifers in Texas reservoirs and streams. And, those available were usually obtained coincidental to the results of other studies (Marsh et al., 1978; Harrel, 1973). Aside from extensive reports of rotifer populations in the Great Lakes by Harring and Mayer (1922) and Stemberg (1979), only a few reports can be found for the whole of North America. There have been lists of rotifers published from Florida (Ahlstrom, 1934), Louisiana (Gallagher, 1966), and Oklahoma (Taft, 1932). This research was conducted to provide a list of species of the genus *Brachionus* in northeastern Texas (with illustrations to assist in identification).

Methods

This report is based on weekly study of the rotifers occurring in Lake Fork, Wood

County, from 1982 to 1985 and from monthly collections from other reservoirs including Lake O' the Pines, Harrison County, and Lake Pat Mayse, Lamar County, from September 1985 to September 1987; Lake Wright Patman, Bowie County, and Lake Lavon, Collin County, from September 1985 to September 1986; and Lake Tawakoni, Hunt County, and Lake Cypress Springs, Franklin County, from October 1986 to September 1987 (Fig. 1). Two samples were taken at each predetermined collecting station from the floating and submergent vegetation zones with 129 meshes per inch nylon plankton nets which were pulled through the water for 90 seconds at low trolling speed. Sampling distances were about 150 meters. Four to seven collecting stations were sampled at each lake, depending upon the size of the lake and the number of inlet streams. Collections were made within the upper 20 centimeters of the surface water and each sample was transferred to a 150 milliliter specimen jar and placed on ice in an ice chest for transportation to the laboratory. Two samples were taken at each collecting station. Microscopic examinations of at least 20 wet-mounts were examined from each sample. Available keys (Stemberger, 1979; Voight and Koste, 1978; Edmondson, 1959; Pennak, 1978) were used for identification. Species identifications were accepted only if confirmed by two or more of the investigators.

RESULTS

The genus *Brachionus* is a member of the family Brachionidae, Order Ploima, and Class Monogononta of the Rotaria. Species of this genus are bilateral and possess a single ovary within a stiff, thickened lorica with two, four, or six spines on the anterior margin. Posterior spines may be present. There is an elongate, annulated foot with two short toes. Approximately 30 species of this genus are known and are among the most frequently encountered rotifers world-wide, but there are no precise lists of the genus available for Texas waters. All species are indicators of eutrophication (Stemberg, 1979). Eleven species of *Brachionus* (Fig. 2), were identified from northeastern Texas reservoirs during the investigation. An account of the occurrence of each species is given below and in Tables 1 and 2.

B. angularis Gosse, 1851 (Fig. 2a).—This species occurred in all seven of the reservoirs sampled and was identified from one or more of the reservoirs in each month of the year. It may be considered as nonseasonal because it occurred in Lake Pat Mayse and Lake O' the Pines during the months of February through November and from Lake Tawakoni during all months except September and December. Identifications from Lake Cypress Springs were made in March, July and August. This species occurred in all of the reservoirs in July and in six of the reservoirs in August and October. The only December identification was from Lake Fork, and January identifications were from Lake Fork and Lake Tawakoni.

B. bidentata Anderson, 1899 (Fig. 2b).—This species occurred in all seven of the reservoirs sampled and was present in all months except December and January. It may be considered a non-seasonal species. It occurred in September, November, April, July, and August in Lake

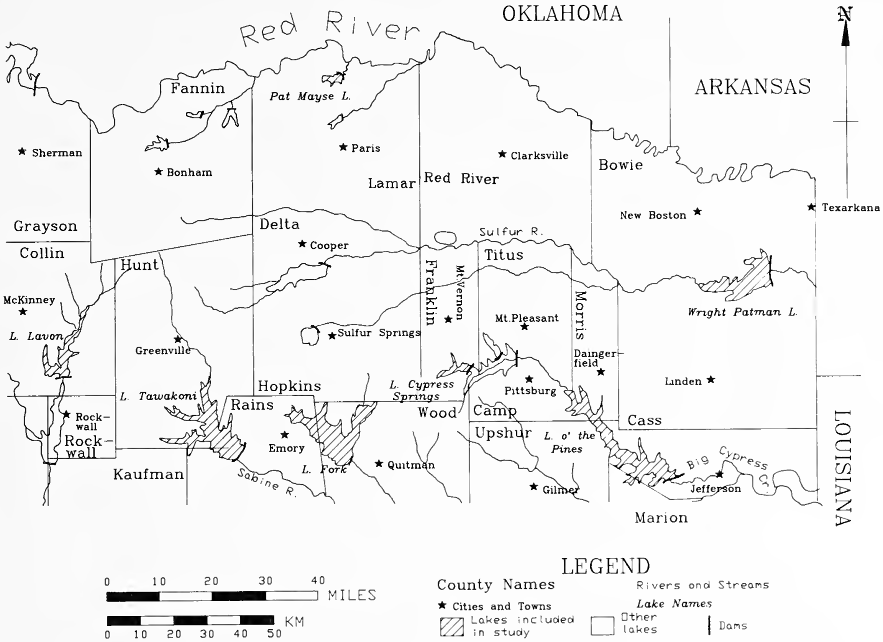


FIGURE 1. Northeastern Texas showing the locations of the lakes included in this study of the occurrence of members of the genus *Brachionus*.

Wright Patman and in Lake Tawakoni in October, November, February, May, and June. It was observed in Lake Lavon in September and October and in Lake Cypress Springs in July. The species was identified during November, March, and July from Lake Fork, during May and August from Lake O' the Pines, and during April, June, July, and August from Lake Pat Mayse. The species occurred in five of the reservoirs during August and in four of the reservoirs during July and October. The only February identification was from Lake Tawakoni. It was identified from two different reservoirs each month in March, April, May, June, and September.

B. budapestensis Daday, 1885 (Fig. 2c).—This species was identified from Lake Pat Mayse, Lake O' the Pines, Lake Lavon, and Lake Tawakoni. The occurrence of the species in September, October, November, March and June suggests that it requires the cooler temperatures of autumn and spring and does not thrive in the colder winter months nor in the hotter summer months. Identifications were made during the three fall months from Lake Lavon and only once from the other reservoirs.

B. calyciflorus Dallas, 1766 (Fig. 2d).—This species was identified from all the reservoirs except Lake Cypress Springs. It was found only once in Lake Fork. This species may be a cool weather species because

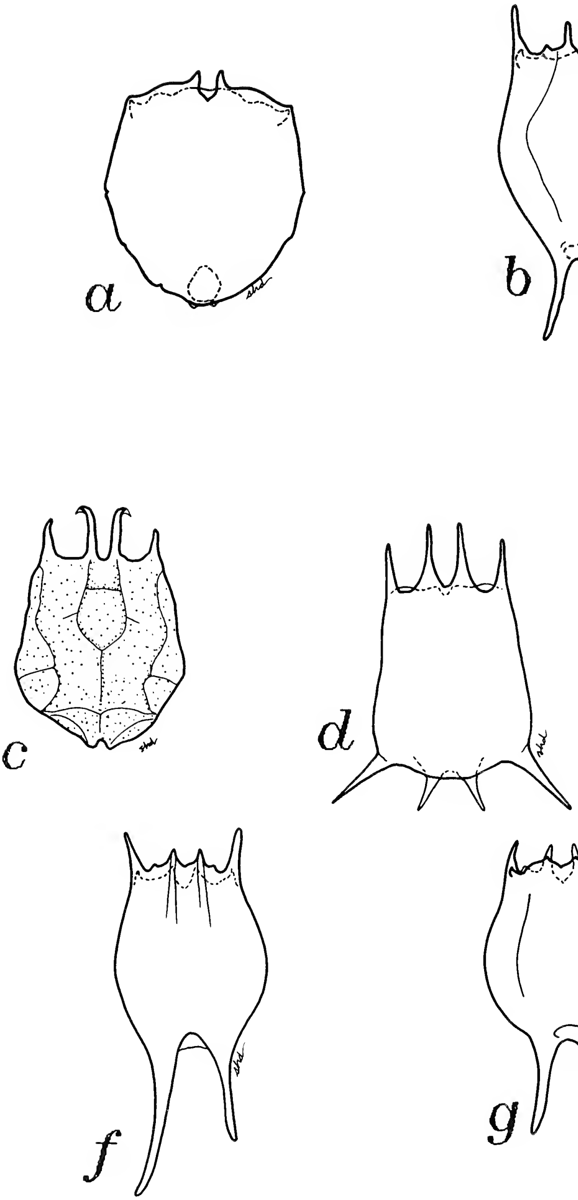
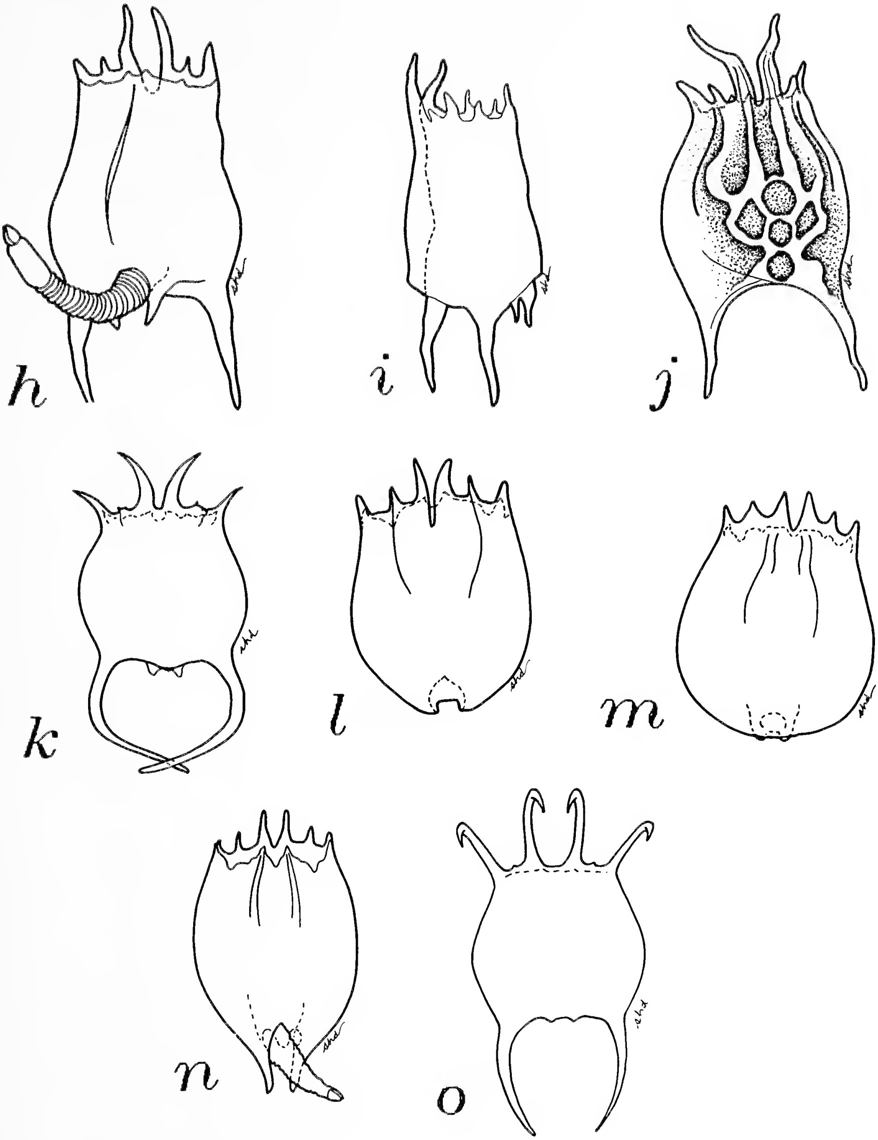


Figure 2. Species of *Brachionus* which have been observed in northeastern Texas. a = *B. angularis*; b = *B. bidentata*; c = *B. budapestensis*; d = *B. calyciflorus*; e = *B. caudatus*; f, g = *B. havanaensis*; h, i, j = *B. quadridentatus*; k = *B. quadridentatus* (English form); l = *B. rubens*; m = *B. urceolaris*; n = *B. variabilis*; o = *B. zahnisera*.



it was found in four of the reservoirs from February through April and from September through November. An exception to this was its occurrence in Lake Lavon in May and July as well as in January. This species occurred in five reservoirs in September, and in four different reservoirs in February and March.

B. caudatus Barrois and Daday, 1894 (Fig. 2e).—This species was found in all the reservoirs except Lake Cypress Springs. It occurred in

Table 1. The monthly occurrence of species of the genus *Brachionus* in northeastern Texas reservoirs, 1983-1987.

Species	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
B. angularis	+	+	+	+	+	+	+	+	+	+	+	+
B. bidentata	+	+	+			+	+	+	+	+	+	+
B. budapestensis	+	+	+				+			+		
B. calyciflorus	+	+	+			+	+	+				
B. caudatus	+	+	+		+			+	+	+	+	+
B. havanaensis	+	+	+		+		+		+		+	+
B. quadridentatus	+	+	+		+	+	+	+	+	+	+	+
B. rubens	+	+			+			+			+	+
B. urceolaris	+	+	+				+	+	+	+		+
B. variabilis		+					+				+	
B. zahnisera								+				

six reservoirs in July, in five reservoirs in August, and in four reservoirs in September and October. It may be regarded as a warm weather species because it occurred most frequently among the reservoirs during May through October. In addition, there was a January identification from Lake Fork, an April identification from Lake Wright Patman, and a November identification from Lake Fork and Lake Lavon.

B. havanaensis Rousselet, 1911 (Fig. 2f, g).—This species occurred in all seven of the reservoirs sampled. It was identified from six reservoirs in October and from five reservoirs during July, August, September, and October, suggesting that warmer temperatures of the summer and early fall were most favorable. The species only occurred in Lake Tawakoni in October and in Lake Fork in November, January and May. Identifications were made from Lake Wright Patman in March and from Lake O' the Pines in May in addition to the summer months.

B. quadridentatus Herman, 1783 (Fig. 2h, i, j, k).—This species was identified in samples from all seven of the reservoirs and occurred in at least one reservoir in every month except December. It occurred in five lakes in July, four lakes in November, and three lakes in May, June, August and September suggesting that the conditions of summer, autumn, and late spring were most favorable throughout the region. The species only occurred in Lake Fork in January and February, in Lake Lavon in March, in Lake O' the Pines and Lake Lavon in April, in Lake Pat Mayse and Lake Tawakoni in June and in Lake Fork and Lake Lavon in November. The only identification from Lake Tawakoni was in June and the only identification from Lake Cypress Springs was in July.

B. rubens Ehrenberg, 1938 (Fig. 2l).—This species occurred in Lake Fork in January, Lake Lavon in October, Lake Wright Patman in

TABLE 2. The distribution of species of the genus *Brachionus* in seven northeastern Texas reservoirs.

Species	Reservoirs*and sampling periods						
	LF	LL	LWP	LOP	LPM	LT	LCS
	82-85	85-86	85-86	85-87	85-87	86-87	86-87
B. angularis	+	+	+	+	+	+	+
B. bidentata	+	+	+	+	+	+	+
B. budapestensis		+		+	+	+	
B. calyciflorus	+	+	+	+	+	+	
B. caudatus	+	+	+	+	+	+	
B. havanaensis	+	+	+	+	+	+	
B. quadridentatus	+	+	+	+	+	+	
B. rubens	+	+	+		+		
B. urceolaris	+		+	+		+	
B. variabilis	+		+			+	
B. zahnisera				+			

*LF = Lake Fork, LL = Lake Lavon, LWP = Lake Wright Patman, LOP = Lake O' the Pines, LPM = Lake Pat Mayse, LT = Lake Tawakoni, LCS = Lake Cypress Springs

April, July and September and in Lake Pat Mayse in July, August, and October. Its presence in July through October may indicate that the species does well in the warmer periods of summer and early autumn.

B. urceolaris Mullens, 1773 (Fig. 2m).—This species was identified in October from Lake Fork, Lake O' the Pines, Lake Wright Patman, and Lake Tawakoni. Two identifications were made in May from Lake Fork and Lake Tawakoni. Identifications were also made from Lake Lavon in April and November, from Lake Wright Patman in March, August, and September, and from Lake Tawakoni in June and August. The pattern of occurrence suggests that the cooling water temperatures of winter were unfavorable for its activities.

B. variabilis Hempel, 1896 (Fig. 2n).—This species was identified in March from lakes Fork, Wright Patman, and Tawakoni. It was collected in July and October from Lake Pat Mayse. The cool waters of spring and fall may be most suitable for this species.

B. zahnisera Ahlstrom, 1934 (Fig. 2o).—Several specimens were identified from a sample from Lake O' the Pines in April.

DISCUSSION

Due to the brief periodicity of all species of *Brachionus*, relative population sizes are not given. Abundant species could become rare in a few days, common species could be increasing or decreasing, and rare species could be increasing or disappearing. Failure to collect a species in any given month might also have resulted from its periodicity.

Brachionus angularis, B. bidentata, and *B. havanaensis* occurred in all of the seven lakes studied. *Brachionus quadridentata, B. caudatus* and *B. calyciflorus* occurred in all lakes except Lake Cypress Springs. *Brachionus budapestensis* occurred in Lake O' the Pines, Lake Lavon, Lake Tawakoni, and Lake Pat Mayse. *Brachionus urceolaris* was found in Lake O' the Pines, Lake Fork, and Lake Tawakoni. *Brachionus variabilis* and *B. rubens* occurred in Lake Fork and Lake Pat Mayse. *Brachionus zahnisera* occurred only in Lake O' the Pines. The data suggested that distribution of the eleven species of *Brachionus* was probably not dependent on pH, as six species were found in lakes ranging between pH 6.9 and 8.5. Conversely, *B. zahnisera* was present in Lake O' the Pines (pH 8.5) but not in Lake Wright Patman, Lake Tawakoni, Lake Cypress Springs, or Lake Pat Mayse with similar pH values.

The occurrence of four of the species was not dependent on seasonal changes. *Brachionus angularis, B. bidentata, B. havanaensis* and *B. quadridentata* were present throughout the year in most of the lakes and were not seasonally restricted in any lake. *Brachionus caudatus* was collected from April to November, but was not present from December through March. Conversely, *B. calyciflorus* was not collected in any reservoir from June through August, but was identified in samples collected from September through April. The occurrence of *B. budapestensis* may be governed by seasonal conditions since it was identified during May and June and from September to November. A seasonal pattern could not be established for the remaining species as *B. urceolaris* was identified in May, June, and October; *B. rubens* was identified in January, July, and October; *B. variabilis* was identified in May and October; and *B. zahnisera* was identified from a single sample in April.

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FIRST TEXAS RECORD OF *GEOPLANA ARKALABAMENSIS* (TURBELLARIA: TRICLADIDA: TERRICOLA) WITH A REVIEW OF OTHER LAND PLANARIANS REPORTED IN THE STATE

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Abstract.—The first known Texas population of the land planarian *Geoplana arkalabamensis* Ogren and Darlington, 1991, is reported. Three additional species of land planarians previously reported from Texas [*Caenoplana coenoplana vaga* (Hyman, 1943), *Kontikia mexicana* (Hyman, 1939), and *Bipalium kewense* Moseley, 1878] are reviewed and new descriptive information is given for all four species. New state localities are given for *B. kewense*. *Key words: Geoplana arkalabamensis; Bipalium kewense*; land planarians; Texas.

Land planarians most commonly occur in the warmer regions of North America, but due to their secretive habits and often sporadic occurrence, they are considered rare compared to other soil biota. This paper reports the first Texas locality of *Geoplana arkalabamensis* Ogren and Darlington, 1991, and expands and updates current knowledge on this species and three others previously reported from Texas. For a complete review of known species, geographic distributions, nomenclature, synonyms, and relevant literature consult Ball and Sluys (1990), Ogren and Kawakatsu (1988, 1990, 1991, 1992), Ogren et al. (1992), and Winsor (1983).

Materials and Methods

Living specimens were collected by hand with a moist camel hair brush, placed in a glass jar with a wet paper towel, and stored in a refrigerator until studied or preserved. Optimum preservation results were obtained when specimens were flooded with boiling water while extended on an enamel or Teflon® surface, fixed in FAA solution (90 milliliters 50 percent ethyl alcohol, 5 milliliters formalin, 5 milliliters glacial acetic acid) for 24 hours, and preserved in 70 percent ethanol. Specimens were examined in glycerol or dehydrated in ethyl alcohol, cleared in xylene, and examined as whole mounts. Voucher specimens were deposited in the United States Museum of National History in Washington, D.C. and retained in the collections of Harrel and Ogren.

Results and Discussion

A population of the recently described land planarian *Geoplana arkalabamensis* was discovered living near a residence at 9250 J Hood Street, Beaumont, Jefferson County, Texas. The site has clay soil and was a rice field about 15 years ago. Jefferson County is the most southeasterly county in Texas and it borders the Gulf of Mexico. Approximately 25 specimens were collected from July through December 1991. Five additional specimens were collected in May 1993. Numerous specimens were observed during each month of the year, except January and February, for the past seven years. Specimens were observed or collected during early morning hours or after dusk moving over concrete driveways, sidewalks, or on the side of concrete house slabs. During the day individuals were found under bricks, rocks, logs, and boards. Specimens were never observed moving about during periods of low rainfall or low nightly humidity.

Geoplana arkalabamensis was originally described from only six specimens: one from Little Rock, Pulaski County, Arkansas and five from Monroeville, Monroe County, Alabama (Ogren and Darlington, 1991). This Beaumont, Texas locality, 547 km southwest of the Arkansas site and 660 km west of the Alabama site, represents the most southern and western collection locality for this species. While the origin of the Beaumont population is unknown, it probably was accidentally introduced on plants or in soil by human activity. As in all other species of land planarians reported in North America, *G. arkalabamensis* is believed to be an introduced, exotic species. Consequently, distributions are generally discontinuous and restricted to sites of introduction (Ogren, 1986; Ogren and Darlington, 1991).

Amended descriptions of *G. arkalabamensis* and three other species of land planarians previously reported from Texas, with annotations, are given below.

Geoplana arkalabamensis Ogren and Darlington, 1991, [Family Geoplanidae Stimpson, 1957; Subfamily Geoplaninae Ogren and Kawakatsu, 1990].—Body elongate, flattened with rounded sides, tapered both anterior and posterior, with maximum width just anterior to the mouth. Anterior 1-2 millimeter (mm) of body very thin and in living specimens was observed to be elevated above the substrate and moved from side to side during forward movement; this area is often recurved dorsally in preserved specimens. Dorsal coloration is black or blue-black and a narrow mid-dorsal unpigmented zone extends the length of the body in most specimens. A single row of variable sized ocelli border the anterior margin and the first 2-3 mm of the lateral margin; these ocelli are not visible from the dorsal surface. The anterior lateral ocelli are followed by many rows of smaller ocelli that converge dorsally to near the midline and extend posteriorly until the unpigmented zone occupies the entire dorsal surface. The small dorsal ocelli are arranged in close rows and contribute significantly to the intense black dorsal color. Most of the dorsal ocelli were not visible until the specimens had been examined in glycerol or dehydrated and cleared. The ventral surface consists of a large creeping sole which is light yellow to pale brown or pale gray. The mouth and gonopore are surrounded by unpigmented regions and are located ventrally behind the mid body region. Living specimens were 25-65 mm long, 3-10 mm wide, and <1-1.5 mm thick. Preserved specimens were 5-10 mm shorter.

Caenoplana coerulea vaga (Hyman, 1943) (Family Geoplanidae, Subfamily Caenoplaninae Ogren and Kawakatsu, 1991).—When redescribed by Ogren (1989) the species was considered conspecific with *Caenoplana coerulea* Moseley, 1877, and designated a geographic subspecies. Body elongate and flattened; color dark blue dorsally with a narrow median yellowish zone terminating in an anterior white tip. Microscopic examination revealed that the blue coloration is in the rhabdites. The ocelli are arranged in a single row on the anterior tip and extend along the lateral margin, but not dorsally. Body length to 60 mm and four mm wide. Reported from a residential garden in San Antonio, Texas by Barnwell (1978). The identity of these specimens remains uncertain due to the inadequate description and lack of voucher specimens. Barnwell (1978) listed the length (40-60 mm) and width (4-7 mm) dimensions and stated that the color was "blue-black". *Caenoplana coerulea vaga* is not blue-black and has a yellow mid-dorsal line. The blue pigment is in the rhabdites and there is no black pigment in the tissues. This raises the possibility that the specimens reported by Barnwell (1978) might actually have been *G. arkalabamensis* which was undescribed at the time. Other North American localities reported for *C. vaga* are from California, Florida, and Georgia (Ogren, 1989).

Konikia mexicana (Hyman, 1939) (Family Geoplanidae, Subfamily Caenoplaninae),—The dorsal surface has three dorsal black stripes (Ogren, 1990); one black narrow median stripe bordered by pale zones and two broad lateral black stripes bordered on the sides by pale zones. A dark stripe extends along the lower border of the lateral pales zone. To the casual observer, specimens appear uniformly black. Ocelli are in a single row across the dorsal anterior tip and extend posteriorly into the pale zone. The ventral surface is a creeping sole which has two broad dark stripes separated by a median pale zone. Body to 38 mm long and five mm wide. The only Texas record is from Hyman (1939, 1943) from specimens collected in Laredo, Webb County, Texas on potted plants being imported from Mexico. There is no known locality in Mexico and other known localities reported from North America are in Arizona, California, and Washington (Ogren, 1990).

Bipalium kewense Moseley, 1878 (Family Bipaliidae von Graff, 1896)—Body elongate, strape-shaped; head semilunar with posterior margin virtually straight without recurved auricles. Dorsal coloration blotchy brown to yellow-ochre with five black to violet stripes that extend the length of the body. Numerous ocelli located around the periphery of the head and extend along the body margin to the posterior. Ventral color light yellow-ochre with two diffuse black stripes that originate near the neck and border the creeping sole. Body to 350 mm long. Winsor (1983), Ogren (1985), and Neck (1987) reviewed the distribution of this species. Published Texas records are from: Harris County, Houston (Tramell and Campbell, 1971); Bexar County, San Antonio (Ogren, 1985); Cameron County, Brownsville; Comal County, New Braunfels; Travis County, Austin; Kendall County, Guadalupe River State Park; San Saba County, Gorman Falls State Park; and Walker County, Huntsville (Neck, 1987). New Texas localities for *B. kewense* resulting from this study are from Jefferson County, Beaumont; Hardin County, Silsbee; and Orange County, Orange. In agreement with Neck (1987), *B. kewense* is well established in southeast Texas and has been observed and collected from under bricks, stones, logs, boards, and in soil and compost areas where earthworms, upon which it feeds, are abundant.

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RED IMPORTED FIRE ANT IMPACT ON WILDLIFE: AN OVERVIEW

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ABSTRACT.—We reviewed the past 50 years of literature concerning red imported fire ant impacts on wildlife species. The red imported fire ant has had a negative impact on numerous species of wildlife. However, experimental evidence of population-level impacts is meager. We discuss potential fire ant perturbations and suggest research directions that may settle the long-standing controversy concerning the impact of imported fire ants on native vertebrates and the ecosystems they have invaded. *Key words*: exotic impacts; red imported fire ant; polygyne; *Solenopsis invicta.*

Red imported fire ants (*Solenopsis invicta*) (RIFA) were introduced from the South American Pantanal area into the United States through the port of Mobile, Alabama, in the early 1930s (Vinson and Sorensen, 1986). Despite federal control efforts initiated in 1958 (Hinkle, 1982), over 101,000,000 hectares in the United States are currently infested, and red imported fire ants are expected to infest almost one quarter of the Untied States before range limits are reached (Vinson and Sorensen, 1986).

Introductions of most exotic species fail (Simberloff, 1981), but some succeed and exert impacts ranging from relatively benign to destructive (Elton, 1958; Diamond and Case, 1986). Introduced predators have produced the greatest impact on native ecosystems (Diamond and Case, 1986; Vitousek, 1986). Perturbations by exotics on one trophic level of an ecosystem may indirectly cause changes at other levels (Carpenter et al., 1985).

A native fire ant (*S. geminata*) is considered a keystone predator, suppressing herbivores and predators in some habitats (Risch and Carrol, 1982). The red imported fire ant is an aggressive congener known to disrupt arthropod communities in the United States (Porter and Savignano, 1990).

The first reports of RIFA-caused mortality in vertebrates surfaced in the United States during the 1940s. Recent occurrences of RIFA colonies with multiple fertile queens (Glancey et al., 1973), and the high mound densities associated with these polygyne colonies, have renewed interest in RIFA impacts on native vertebrates and compounded the problems created by fire ants.

A mature colony of RIFAs may contain 200,000 or more individuals (Lofgren and Vander Meer, 1986), and mound densities may reach 1,400 colonies/hectare (Maxwell et al., 1982). When occurring at high densities, RIFAs dominate food sources (Vinson, 1990), other ants are outcompeted (Vargo and Porter, 1989; Porter et al., 1988; Vinson, 1990), native ant and other arthropod diversity decreased (Porter and Savignano, 1990), and vertebrates may be negatively affected (Maxwell et al., 1982).

A taxonomic history is beyond the scope of this paper, but it is necessary to clarify a point of confusion. Prior to the 1970s the taxonomic status of the imported fire ants was unclear (Buren, 1972). Two species of imported fire ant are now recognized, the red, and the black (*S. richteri*). Today *S. richteri*, outcompeted and displaced by *S. invicta*, occupies a limited range in northeast Mississippi and northwest Alabama, whereas *S. invicta* occurs throughout the remainder of the infested area. It is impossible to distinguish between the two species using references prior to the early 1970s.

Although current research focuses on many RIFA-vertebrate interactions, review and synthesis of literature on these interactions are lacking (Lutz and Demararis, 1990). Here we review and synthesize information published since 1948 concerning RIFA impacts on reptiles, birds, and mammals.

Impacts on Reptiles

Several reptile species in the southern United States are declining in all or parts of their range. RIFAs are often suggested as a contributing factor. For example, the Texas horned lizard (*Phrynosoma cornutum*) has been largely extirpated from eastern Texas (Price, 1990), in an area that coincides with the RIFA range in the state, and the RIFA has been suggested as a causal factor (Price, 1990; Goin, 1992). The invertebrate diet of many reptiles may overlap with the diet of RIFAs. Moreover, reptile life histories often include an egg stage vulnerable to RIFA predation.

Landers et al. (1980) reported RIFAs as predators on the hatchlings of the gopher tortoise (*Gopherus polyphemus*) in southwestern Georgia. Monitoring 38 nests in eight tortoise colonies, the authors discovered that mortality from various sources was high and only four nests (11%) survived incubation intact. While the majority of nest destruction occurred during incubation, RIFA-induced mortality occurred at the hatchling stage. Ten hatchling tortoises were killed by RIFAs.

Mount et al. (1981) presented convincing experimental evidence that RIFAs would attack and consume eggs of the six-lined racerunner (*Cnemidophorus sexlineatus*) in Alabama. Mount (1981) speculated that several reptile species were declining as a result of RIFA predation.

Many amphibian and reptile species may be vulnerable either to direct or indirect RIFA impact due to shared food habits with RIFAs and an egg stage vulnerable to RIFA predation. Difficulites with *in* *situ* herpetological studies make assessment of RIFA impact on amphibian and reptile populations formidable.

Impacts on Wild Birds

The literature contains numerous references to RIFA predation on birds. Ridlehuber (1982) suggested that high RIFA foraging use of nesting cavities (70%) precluded use by wood ducks (*Aix sponsa*), and observed RIFA predation on wood duck nestlings and pipped eggs. Sikes and Arnold (1986) monitored cliff swallows (*Hirundo pyrrhonota*) in east-central Texas and found nest success was 41% with RIFAs present, compared with 75% success when RIFAs were controlled in nesting areas the following year. The authors considered the RIFA to be a major problem for cliff swallows in the vicinity of their study area.

Wilson and Silvy (1988) included a number of observations of predation on individual birds, including Attwater's prairie chicken (*Tympanuchus cupido attwateri*), northern bobwhite (*Colinus virginianus*), and scissor-tailed flycatcher (*Muscivora forficata*). Mount (1981) attributed the decline of the common nighthawk (*Chordeiles minor*), common ground-dove (*Columbina passerina*), and eastern meadowlark (*Sturnella magna*) to RIFA predation in southern Alabama. Hays (1980) observed nine cases of fire ant predation on least tern (*Sterna albifrons*) chicks. Interest in the impact of the RIFA on nesting least terns remains high, and additional research is underway (T. Lockely, U.S.D.A., APHIS, S&T, Imported Fire Ant Lab, Gulfport, MS, pers. comm.). Others mention incidental RIFA predation on various avian species (Rankin, 1957; U.S. Agric. Res. Serv., 1958; Hays and Hays, 1959; U.S. Dept. Agric., 1968; Ashdown, 1969; Lofgren, 1986; Lofgren and Vander Meer, 1986).

Red imported fire ants on offshore barrier islands in the ship canal of Houston, Texas, were manipulated to determine the impact on nesting shore birds (e.g., great egrets, *Casmerodius albus*) (B. Drees, Texas A&M Univ. Agric. Exp. Stn., pers. comm.). Preliminary results indicated that during times of low fire ant activity (cool weather), RIFA impact on nesting birds was minimal, but predation on nests of late-nesting individuals was high.

Interest and controversy concerning RIFA predation on northern bobwhite continues. Fire ants were first reported as a source of quail mortality by Stoddard (1931) and Travis (1938*a,b*). Travis (1938*a*) documented yearly (1924-1937) native fire ant predation on bobwhites ranging from one to nine percent ($\bar{X}$=6.5%), and speculated that the decline of the ground-dove in Florida was attributable to fire ants.

Other researchers have de-emphasized the role of fire ants as a predator of quail (Brennan, 1991; Komarek, 1980). Johnson (1961) concluded, despite observing a six percent RIFA-induced quail chick mortality, that RIFAs had little, if any, effect on quail populations. Dewberry (1962) reported that 12% of hatching quail eggs were destroyed by fire ants, but noted that incubating birds were undisturbed by ants. Simpson (1976) observed only one of 1,725 quail nests in Georgia destroyed by fire ants. Rankin (1957), Wheeler (1958), Ashdown (1969), and Sterling and McDaniel (1978) mentioned imported fire ants as potential quail predators.

Impacts on Mammals

Deaths of wild mammals due to the RIFA first surfaced as anecdotal reports in the late 1940s. Biologists working with landowners in RIFA-infested areas regularly hear of blinded or dead white-tailed deer fawns (*Odocoileus virginianus*) (Rollins, 1989) or other mammals apparently harmed by the RIFA. These incidences, however, are rarely definitive evidence of RIFA-induced mortality in mammals.

Bruce et al. (1949) included the first report of mammal losses due to the RIFA, specifying the loss of newborn rabbits (*Sylvilagus* sp.) and squirrels (*Sciurus* sp.). Ten years later (U.S. Agric. Res. Serv., 1958) it was stated that there were no published reports of RIFA predation on birds or other animals, yet this report again cited the RIFA as a "destroyer" of newborn small mammals. A decade later RIFAs were still implicated in the deaths of newborn rabbits and squirrels (Ashdown (1969).

Ashdown (1969) included an account by a rural Florida couple who reported an increase in quail and wild rabbit populations following fire ant treatment with Mirex®. Reported wildlife kills increased in Georgia in the 1960s following RIFA population increases (Irvin, 1980). By 1970, public sentiment had turned against the use of Mirex® for RIFA control, and Coon and Fleet (1970) published a paper decrying the use of Mirex®. To support their stance, they de-empahsized the effect of the RIFA on mammals and other animals. At that time, little experimental evidence documented RIFA-wildlife interactions, and arguments concerning effects of RIFAs on wildlife populations were moot.

Hill (1969, 1972) quantified the loss of captive nesting cottontail rabbits (*S. floridanus*) to imported fire ants in Alabama from 1963-1967. Of 101 litters born in the 15 x 15 meter pens, 16% were destroyed by fire ants. In 61 x 61 meter pens, 81 litters were observed and 50% were destroyed. Of 43 litters born in large enclosures, 23% were destroyed. Hill observed that young cottontails and *Rattus norvegicus* were most vulnerable from birth to four days old. After this age the young mammals were more mobile and had enough fur to prevent stinging over large portions of their bodies.

Newsom et al. (1976) published the results of a study on fire ant-muskrat (*Ondatra zibethicus*) relationships in Louisiana coastal marshes. No significant association was discovered, but most muskrat houses was examined between reproductive peaks.

Fire ant-induced mortality of live-trapped small mammals has been documented by Masser and Grant (1986) and Flickinger (1989). One of 33 hispid cotton rats (*Sigmodon hispidus*), nine of 38 pygmy mice (*Baiomys taylori*), three of 23 white-footed mice (*Peromyscus leucopus*), and zero of eight fulvous harves mice (*Reithrodontomys fulvescens*) were killed by RIFAs, averaging 13% mortality overall (Masser and Grant, 1986). Checking traps at three-hour intervals did not reduce mortality. Flickinger (1989) recorded 20 to 225 (9%) captured hispid cotton rats killed by RIFAs despite attempts to reduce attractiveness of live traps. Additionally, 13 rats (6%) were covered with ants and partially devoured. Hill (1972), Masser and Grant (1986), and Flickinger (1989) indicated that RIFA-induced mortality was less during cool seasons and cold weather.

Smith (1988) and Smith et al. (1990) documented the avoidance of areas with high fire ant densities by northern pygmy mice (*Baiomys taylori*), and suggested similar avoidance patterns for some other rodent species. Grant and Killion (1988) included a number of observations of individual mammals killed by the RIFA. Killion et al. (1990) presented preliminary data which suggested that hispid cotton rats avoided areas of high fire ant density. The authors offered possible reasons for avoidance behavior, such as lowered reproductive success due to RIFA predation on nestlings, competition for food, or simple "harassment" caused by RIFA stings.

Implications and Research Needs

Sound management decisions are conditional on quantification of RIFA effects on wildlife at the population level, but the effect of RIFA on wildlife populations is poorly understood. Consequently, we can only speculate on management implications and suggest research needs that will lead to a better understanding of fire ant influences on wildlife.

The RIFA has the potential of impacting many vertebrate and invertebrate species. RIFAs favor open and semi-open habitats; preferences that are shared with many wildlife species. Foraging activity of the RIFA is temperature dependent, with most foraging activity occurring when soil temperatures are between 22-36° C at a depth of two centimeters (Porter and Tschinkel, 1987). This temperature range coincides with peak reproductive activity of many vertebrate species. Fire ants are attracted to mucous (Vinson and Sorensen, 1986), and newborn animals may be vulnerable to RIFAs.

Moreover, heavy RIFA foraging may preclude use of some habitats by vertebrates (and invertebrates) because of irritation from RIFA stings.

Red imported fire ants are efficient opportunist foragers and may outcompete both vertebrates and invertebrates for favored food sources. RIFAs simplify invertebrate communities (Porter et al., 1988; Porter and Savignano, 1990). Key native elements of the food chain may be supplanted by the RIFA, with potential negative effects on native species not directly impacted and on ecosystem properties.

While we know that individuals of many species may be killed by the RIFA, we do not know the effect of RIFAs on vertebrates at the population level. Additional passive anecdotal evidence and experiments of small scope will not provide an understanding of the complex interactions between vertebrate populations and RIFAs. To gain an understanding of the effects of the RIFA on vertebrates we need long-term comprehensive ecological studies that encompass populations of target vertebrates, and are conducted with controls and adequate temporal and spatial replication (Hurlburt, 1984). Small-scale studies do not adequately account for animal behavior in natural habitats where RIFA density is seldom homogeneous, but instead is a mosaic of areas having high and low density infestations. Consequently, a multi-disciplinary approach (e.g., entomologists and wildlife biologists) is needed to address potentially confounding effects, such as the reinfestation of treated monogyne areas with polygyne RIFA colonies. Although comprehensive ecological studies pose logistical problems (Eberhardt and Thomas, 1991), they are the most likely to generate useful data.

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VEGETATIONAL CHANGES DUE TO PRESCRIBED FIRE IN MISSION TEJAS STATE PARK

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Abstract.—Park managers are faced with increasing use of recreation areas by the public, so careful management of the park's resources is required to prevent their degradation. Prescribed fire is a widely accepted method for managing and restoring natural ecosystems. Fire can be used to reduce the buildup of hazardous fuels, improve wildlife habitat, enhance aesthetic values, create a diversity of plant communities, and maintain endangered species. A prescribed burn was conducted at Mission Tejas State Historical Park in East Texas to evaluate the effects of prescribed fire on the ecological and aesthetic values of forest stands in the park. Pre-burn and post-burn analysis of sample plots indicated that the fire top-killed woody understory vegetation, but most hardwood species resprouted. Changes also occurred in forest floor coverage. After the fire, leaf litter and shrubs were reduced, while grasses and forbs increased. Overall stand density and diversity was increased, which should provide visitors with a quality recreation experience. *Key words*: prescribed fire, aesthetics, understory vegetation.

In the last few decades, the demand for public outdoor recreation opportunities has increased rapidly. However, the supply of recreation facilities has generally not kept up with the increase in the number of visitors. Park visitors demand a wider variety of services and simultaneously insist on protection of natural ecosystems (Daniel, 1990). This has put a heavy responsibility on managers of parks and wilderness areas to provide adequate outdoor recreation opportunities while protecting their park's natural resources from degradation and decline.

Fire has long been recognized as an important component in natural ecostystems. Many plant communities are specifically adapted to survive fires, and some species, including endangered or threatened species, depend on periodic fire for their continued existence. It is obvious that most recreation areas cannot be left exposed to the damaging and potentially life-threatening effects of random, uncontrolled wildfires. Park managers have learned to use prescribed fire (set under exacting conditions of weather and fuel) to bring about changes in plant and animal communities to preserve the underlying processes of natural ecosystems.

Current fire terminology indicates a prescribed fire can be either initiated by managers or a natural fire occurring under specified conditions in selected wildland areas. A typical prescribed fire is one that is intentionally ignited by managers to accomplish specific objectives. A natural fire ignited by lightning may be allowed to burn so long as it stays within the agency's weather and fire behavior prescriptions. Both fire types are closely monitored to assure they meet management objectives.

BENEFITS OF PRESCRIBED BURNING

Some benefits can be derived from the use of prescribed fire as a park management tool. Fire provides these benefits effectively and with relatively low cost when compared to mechanical or chemical treatments.

Wildlife Habitat Improvement

Burning is highly effective in managing wildlife habitat. A mosaic of burned and unburned areas increases edge effect (transition) between different plant communities, promoting a varied population of wildlife to be enjoyed by visitors.

Burning opens up densely forested sites that develop in the absence of fire and results in an increase in the amount of grasses and sprouts that browsing animals, such as white-tailed deer (*Odocoileus virginianus virginianus*), feed upon (Wade and Lunsford, 1989; Fuller, 1991). Minerals and nutrients from burned forest fuels are released into the soil, which stimulates fruit and seed production, resulting in both a qualitative and quantitative increase in the food supply (Chandler et al., 1983). Ground-dwelling birds, such as wild turkey and bobwhite quail, generally benefit from fires because they can feed on vegetation that grows close to the ground in newly created openings.

Reduction of Hazardous Fuels

Probably the most important goal of prescribed burning is the reduction of forest fuels which tend to build up on the forest floor over time. Previous management policies have sometimes led to hazardous accumulations of fuel because of attempts to exclude all fire from forested environments. The situation is made even more serious by the increasing wildland-urban interface areas (caused by large numbers of people moving into forested areas) that expose more people and property to danger from wildfires. Because of the potential danger of fire escaping, some resource managers are reluctant to use prescribed fire to correct the imbalance of fuels. But these accumulating fuels will ultimately burn. Careful reintroduction of fire in the form of prescribed burning may be the only economical (practical) way to prevent catastrophic wildfires.

Enhancement of Aesthetic Values

Prescribed burning can be used to enhance a park's appearance to visitors by increasing diversity in the park landscape (Wade and Lunsford, 1989). Diversity of view helps to create a more pleasing visual mix of forest vegetation. For example, increased flowers and wildlife make open forest stands more interesting places for hiking. A mixture of burned and unburned stands increases the diversity of view and thus enhances the visual attractiveness of plant communities. Scenic vistas can also be created by burning, enabling the visitor to see interesting landscape features.

Maintain Fire-subclimax Species

Such diverse plant species as longleaf pine (*Pinus palustris*) and pitcher plants (*Sarracenia* sp.) benefit from an active prescribed burning program. Both the Nature Conservancy at Roy E. Larson Sandylands and the National Park Service at the Big Thicket National Preserve have used fire in the management of these and other plant communities (Reeves and Corbin, 1985).

Potential Disadvantages of Prescribed Burning

There are some effects from prescribed burning that may be considered unfavorable for recreational areas, but most of these impacts are relatively short-term. Park resource managers should consider these potential complications and take precautionary steps before a prescribed fire program is initiated.

Smoke and Air Quality

One of the more immediate effects of fire is the short-term degradation of air quality caused by smoke. Burning of organic materials releases water vapor, carbon dioxide, and particulate matter, and some of these compounds are emitted into the air (Reeves, 1977). Many areas have now passed laws that regulate or restrict burning with the intention of reducing air pollution. But the most objectionable effect of smoke in a recreational setting is that it reduces visibility. This effect can be minimized by conducting the prescribed burn in as short a time as possible and by avoiding burning during temperature inversions and other periods of high atmospheric stability (Reeves, 1972; Wright, 1982).

Deleterious Effects on Wildlife

Some species of wildlife can be negatively affected by fire. For example, ground nesting sites can be destroyed by a poorly timed prescribed burn. This problem can be minimized by planning prescribed burns when nesting activity has ceased and by providing ample escape routes for small mammals on the site.

Prescribed fire can also have adverse effects on fish habitat (Wade and Lunsford, 1989). Burning close to a stream or lake could result in silt and sediment entering the aquatic environment. If a fire removes the shading vegetation along a stream, water temperatures can increase to levels that are harmful to fish. Therefore, a buffer zone of litter and vegetation should always be left around riparian or stream-side areas to protect fish habitat.

Attitudes of Visitors

The ash and scorched trees left immediately after a fire can affect the perceived scenic beauty of a forest stand, but burned areas usually recover rapidly and vegetation often surpasses its pre-fire condition. The reaction of the public to the effects of burning depends largely on individual opinions and biases, the type of recreational activity being pursued, and the extent of interpretation efforts employed to inform park visitors. The interpretative efforts of park managers may be most important in shaping the attitudes of visitors toward burning and should be considered when developing a fire management plan.

In most cases, the benefits of using prescribed fire to manage vegetation resources in parks outweigh the negative effects. Although prescribed burning has been used in the past to manage forested recreation areas, more effort is needed to gain public approval for prescribed burning programs. This can best be accomplished by interpretive programs that explain the role of fire in forest ecosystems and park management. Also, additional research is needed to relate the ecological effects of fire to the quality of recreation experiences.

Mission Tejas Prescribed Fire Project

In fall and winter of 1991, through a cooperative arrangement between Texas Parks and Wildlife Department (TPWD) and the College of Forestry at Stephen F. Austin State University (SFASU), a prescribed burning program was initiated at Mission Tejas State Historical Park, located in the Pineywoods vegetation region of East Texas. The park, containing 47.75 hectares, was purchased by local citizens in 1935 and transferred to the Texas Forest Service. The Texas Forest Service operated the park as a demonstration of good forest management practices and for recreational purposes. The park was transferred to the Texas Parks and wildlife Department in 1957. The TPWD is charged with protecting and preserving the natural and historical features within the park.

The park's forested area is an even-aged stand consisting of primarily loblolly pine (*Pinus taeda*) and shortleaf pine (*P. echinata*). This loblolly-shortleaf mixture is the most widespread forest cover type in the southern United States (Mann, 1980). Intermingled with the pines are a variety of hardwoods. The forest floor in most areas of the park was covered with a dense growth of understory vegetation that limited visibility and discouraged access by park visitors. In addition, the accumulation of unburned fuels over time presented an extreme fire hazard to historical structures, park developments, and neighboring private land.

The purpose of the prescribed fire project at Mission Tejas Park is to study the aesthetic and ecological changes caused by using fire to manage natural resources in a recreational setting. The results of the evaluation will be incorporated into an interpretive program that will be applicable in Texas state parks using prescribed fire. This interpretive program will be used to increase the public's knowledge of the role that fire plays in forest ecosystems and to promote the acceptance of prescribed fire as a sound park management practice.

Preparation for Burning

In 1991, park facilities and vegetation types were analyzed, and a 12 hectare section of the park was selected for the study. The following spring, randomly selected parts of the study area were prescribed burned (Fig. 1). Prior to the treatment, a fire management plan was developed. Also, 20 circular plots 1/40 hectare in size were established throughout the fire management area. Ten plots were selected to be burned while the remaining 10 plots remained unburned as controls. The centers of the circular plots were marked with a metal T-post. The area was divided so that burned and unburned sections were equally representative of the vegetation types in the study area, yet both burned and unburned areas would be visible to visitors driving or walking the park road.

A preliminary vegetation survey was conducted in fall 1991 to determine the species composition and density of the understory species in the stand before burning (Table 1). In each sample plot, the sample plot, the species and height of understory vegetation was recorded, and the plot was photographed from each cardinal direction to record vegetation density and visual aesthetics.

To prepare for the prescribed burn, SFASU personnel constructed fire lines with hand tools to control the spread of the fire and to protect areas that would remain unburned. The actual prescribed burn took place in early March, when atmospheric conditions and fuel moisture were within prescription. One of the major concerns of the fire crew during the prescribed burn was protecting the Rice Family Home, a historic log cabin located inside the area to be burned. Extra personnel were stationed around the structure with fire suppression equipment to protect the building.

Post-burn Vegetation Inventory

Four months after the prescribed burn, a second inventory was taken at the sample plots to determine changes in the vegetation composition since the prescribed burn. Since the initial survey did not reveal much variation in the vegetation complex between areas to be burned and those to be left for controls, it was assumed differences observed later primarily would be due to fire effects. The species and height class of each understory species that survived the fire and each sprout originating from plants that had been top-killed were recorded.

At this time, the overstory vegetation was also inventoried. All live trees with a diameter-at-breast-height (dbh) of five centimeters or greater at each plot were tallied. The species, total height, and dbh of each tree in the plots were recorded. Since overstories are seldom altered by a prescribed burn, we did not make a survey until after the first treatment.

To inventory the herbaceous vegetation on the forest floor, four subplots, each 0.2 m^2 in size, were established at the perimeter of each main plot. The frequency of woody species, vines, grasses, and forbs within the subplots was recorded. Also, the percent coverage of the following categories was recorded: shrubs, forbs, grasses, leaf litter, and bare soil. Shrubs included all woody perennials, grasses included herbaceous annual plants, and forbs included all other herbaceous species.

The relative and absolute density of each species of woody vegetation in the understory before and after the prescribed burn was calculated. The results of the two inventories were compared to ascertain any changes in vegetative composition caused by the fire. In addition, the relative and absolute frequency of herbaceous species was determined, and the changes in species composition and frequency between the burned and unburned areas compared.

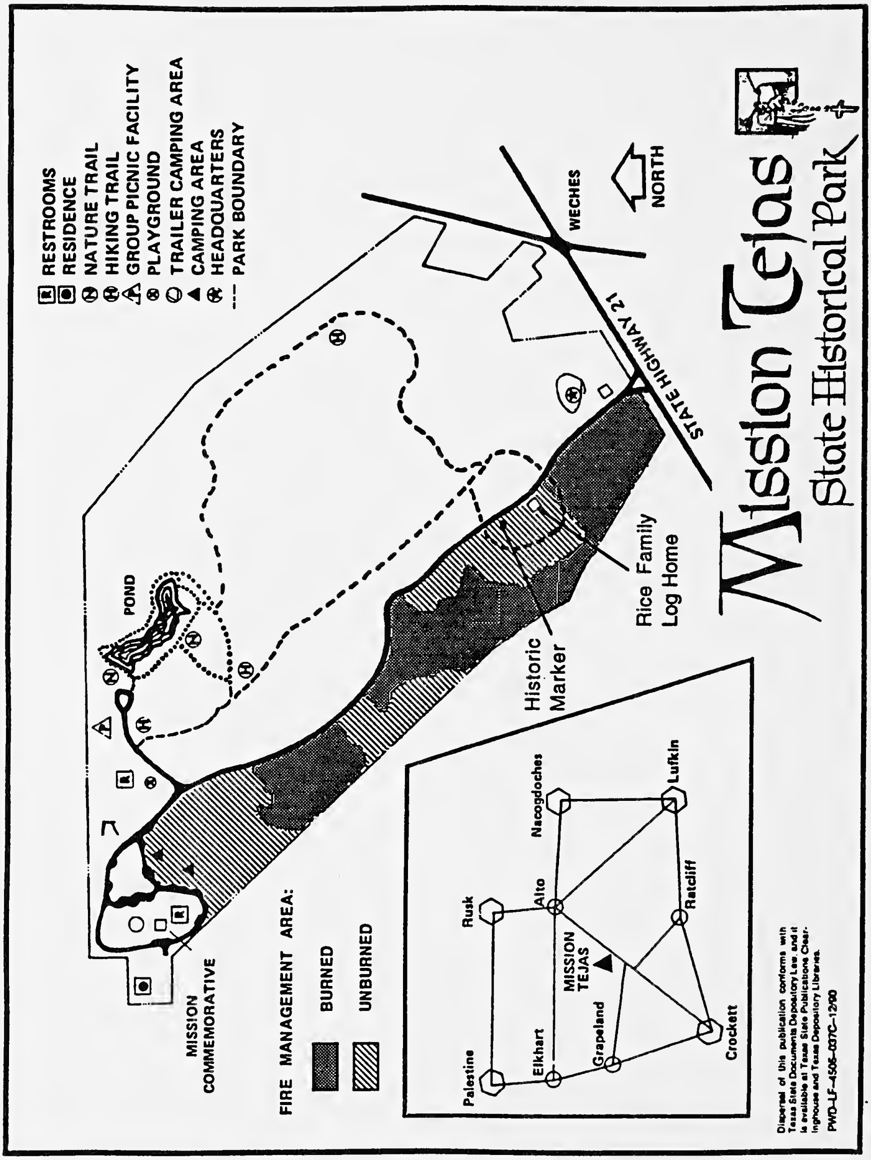

FIGURE 1. Map of the fire management area within Mission Tejas State Historical Park in Houston County, Texas, March, 1992.

TABLE 1. List of woody understory species found in the fire management zone.

Species	Common name
Acer rubrum	red maple
Baccharis halimifolia	eastern baccharis
Bumelia lanuginosa	gum bumelia
Callicarpa americana	American beautyberry
Carpinus caroliniana	American hornbeam
Carya spp.	hickory
Celtis laevigata	sugarberry
Cornus florida	flowering dogwood
Diospyros virginiana	persimmon
Fraxinus americana	white ash
Gleditsia triacanthos	honeylocust
Ilex opaca	American holly
Ilex vomitoria	yaupon
Juniperus virginiana	eastern redcedar
Liquidambar styraciflua	sweetgum
Magnolia virginiana	sweetbay
Morus rubra	red mulberry
Nyssa sylavatica	black tupelo
Ostrya virginiana	eastern hophornbeam
Pinus spp.	pine
Prunus caroliniana	Carolina laurelcherry
Prunus serotina	black cherry
Quercus spp.	oaks
Rhus copallina	shining sumac
Sassafras albidum	sassafras
Ulmus alata	winged elm
Vaccinium spp.	vaccinium
Viburnum rufidulum	rusty blackhaw

RESULTS AND DISCUSSION

Effects on Understory Woody Vegetation

The pre-burn inventory of woody vegetation showed that the most common species in the understory were loblolly and shortleaf pine, with an average of 7,030 seedlings per hectare (Table 2). The second most common species was rusty blackhaw (*Viburnum rufidulum*), a hardwood understory species. Other common species (over 40 stems per hectare) included American beautyberry (*Callicarpa americana*), eastern redbud (*Cercis canadensis*), sweetgum (*Liquidambar styraciflua*), yaupon (*Ilex vomitoria*), vaccinium (*Vaccinium* spp.), and various species of oaks (*Quercus* spp.) and hickory (*Carya* spp.). The total number of woody stems per hectare in the understory was 17,185 before the prescribed burn.

After the prescribed burn, differences in the composition of understory vegetation could be observed between the burned areas and unburned areas within the fire management zone. In the burned areas,

Table 2. Density distribution of common woody species (50 stems per hectare or more) occurring in the fire management zone before and after prescribed burning.

	Stems/hectare		
	Pre-burn	Post-burn	
Species		Burned area	Unburned area
Callicarpa americana	2063	1093	2745
Carya spp.	247	766	220
Celtis laevigata	0	0	56
Cercis canadensis	556	4769	0
Cornus florida	185	642	413
Diospyros virginiana	0	148	54
Fraxinus americana	136	840	0
Gleditsia triacanthos	0	99	27
Ilex opaca	37	0	166
Ilex vomitoria	297	7487	961
Juniperus virginiana	49	0	54
Liquidambar styraciflua	482	1408	371
Magnolia virginiana	0	49	0
Morus rubra	0	0	82
Ostrya virginiana	0	0	109
Pinus spp.	7030	1285	12602
Platanus occidentalis	124	0	0
Prunus caroliniana	0	0	329
Quercus spp.	1903	6548	5024
Rhus copallina	136	1334	193
Sassafras albidum	161	1384	467
Ulmus alata	136	371	301
Vaccinium spp.	395	1581	109
Viburnum rufidulum	3237	3237	3855
Total	17186	36348	27730

the number of pines dropped significantly after the fire. Most of the pine mortality consisted of small seedlings less than three meters in height and smaller than five centimeters in diameter that had not yet developed resistance to fire.

The tops of almost all young hardwoods up to three meters were killed by the fire. Hardwoods generally are much more susceptible to fire injury due to the lack of thick, fire-resistant bark. However, most of the understory hardwood species sprouted readily, and the sprouts of some species, such as yaupon, were so numerous that the toatl number of stems present after the fire greatly exceeded their pre-burn density. The most successful sprouting species in the burned areas were yaupon, various oaks, eastern redbud, and rusty blackhaw (Table 2). Total density for all species nearly doubled the pre-burn density.

In the unburned areas of the fire management zone, the total density of understory vegetation, at 27,730 stems per hectare, was only slightly

TABLE 3. Percent forest floor coverage by vegetation and soil components in burned and unburned areas of the fire management zone.

Forest floor component	Unburned plots	Burned plots
Shrubs	26.2	15.8
Forbs	3.8	7.3
Grasses	8.5	11.0
Leaf litter	58.7	47.5
Bare soil	2.8	18.4
Total	100.0	100.0

less than in the burned areas, but the species composition and density distribution was quite different. A comparison of the species present in the unburned areas with those in the burned areas indicates that the overall understory diversity increased where fire had been used. As in the pre-burn sample plots, the understory of the unburned areas was dominated by pine seedlings, with oaks, rusty balckhaw, and American beautyberry accounting for the majority of additional stems.

The predominance of pine seedlings in the understory of the unburned areas may reflect good regeneration potential due to an especially large seed crop in 1991. Most of the small pine seedlings had not developed secondary needles. Therefore, many of these seedlings apparently germinated after the pre-burn survey, which could account for the smaller proportion of pine seedlings in the pre-burn data.

Effects on Forest Floor Coverage

An analysis of the forest floor after the prescribed burn showed changes in the percent ground coverage in all categories. In the unburned areas, leaf litter covered the greatest percentage of the forest floor, followed by woody shrubs (Table 3). Together these categories accounted for almost 85% of the ground cover. Herbaceous plants occurred somewhat infrequently, and exposed soil was rare. The large amount of pine needles in the litter layer was due to the pine overstory. Shade caused by the combination of overstory trees and dense understory vegetation along with the litter layer hindered the growth of many herbaceous plants which require direct sunlight and limited competition to grow properly.

In the burned areas, the percent coverage by leaf litter decreased by 11.2%, as would be expected after a fire (Table 3). However, much of the burned area was covered with litter of newly fallen leaves and pine needles following the fire.

Coverage by shrubs decreased by nearly 40%, an indication that low woody species had not fully recovered after being top-killed by the fire. Forbs and grasses showed modest increases in coverage. The major limiting factors were apparently shade and the litter layer (which in some areas was not reduced sufficiently by the fire to allow establishment of herbaceous species).

Implications for Park Management

One of the most important effects of the prescribed fire at Mission Tejas State Park was the reduction in the amount of hazardous fuels in the forest stand. The buildup of fuels around the historic Rice Family Home was a cause of concern, because an uncontrolled fire could have easily destroyed the structure. The area around the cabin has now been made more open by the fire and some mechanical clearing, making it much easier for visitors to walk around and explore the structure.

The increase in diversity of woody species following the fire indicates that many species respond well to prescribed burning. If a park manager wished to maintain a diversity of plant species, a mosiac of burned and unburned areas would provide a variety of site characteristics needed to satisfy the ecological requirements of many species. Regular periodic burning would help prevent the return of dense vegetation on selected areas of the park.

The reduction of understory vegetation by the fire also opened up the forest stand, allowing greater visibility from the main park road and the nature trails. It improved wildlife habitat in the fire management area where top-killing of understory vegetation encouraged prolific sprouting, which in turn attracted browsing species such as white-tailed deer. Seed- and fruit-eating birds may find more food among the various grasses and shrubs, especially where crown canopies were more open and litter competition was reduced. However, the production from some fruiting shrubs and small trees may be reduced temporarily as they were top-killed by the fire. Regular prescribed burning for a few years would help keep the woody species suppressed enough to increase the flowering herbaceous component on the forest floor.

The openness of the forest stand, combined with the mature pine overstory, may encourage its use by the red-cockaded woodpecker (*Picoides borealis*), a bird native to East Texas and listed by the U.S. Fish and Wildlife Service as an endangered species. The red-cockaded woodpecker thrives in open, mature pine stands which have minimal hardwood understory/midstory. In the future, some parks may play an increasing role in the management and restoration of endangered species, making prescribed fire an essential management tool.

CONCLUSION

The on-going prescribed fire project at Mission Tejas State Park helps demonstrate the effectiveness and desirability of fire in managing the natural resources of recreation areas. As the land base of natural areas continues to shrink, parks will play an important part in providing areas where natural ecosystems can operate. As the number of visitors to parks continues to increase, it will become even more important for resource managers to apply sound management methods to protect natural ecosystem processes. Prescribed fire is an excellent choice for enhancing ecological values of parks, while still providing a quality recreation experience for the public.

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ESTIMATES OF BROWN BROCKET DEER (*MAZAMA GOUAZOUBIRA*) HABITAT USE AT EL BAGUAL ECOLOGICAL RESESRVE, ARGENTINA

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Abstract.—Brown brocket deer (*Mazama gouazoubira*) habitat use throughout 1988-89 was estimated by track counts in four different plant communities at El Bagual Ecological Reserve, northeastern Argentina. An occupancy index (number of tracks/day) was calculated from repeated readings of 56 track plots (3 m^2). Index variances from the four habitat types sampled were homogeneous and no significant differences ($P>0.05$) in monthly habitat use were found. *Key words*: brown brocket deer; *Mazama gouazoubira*; habitat use; Argentina.

Resumen.—Se estimó el uso del habitat por el guazuncho pardo (*Mazama gouazoubira*) en la Reserva Ecológica El Bagual, en el nordeste de la Argentina, mediante el conteo de huellas en quatro diferentes comunidades vegetales, en 1988-89. A partir de lecturas repetidas sobre 56 círculos de radio fijo de tres m^2 de superficie, se calculó un índice de ocupación (número de huellas/días). Las varianzas de los índices en los quatro ambientes muestreados fueron homogéneas y no se registraron diferencias significativas ($P>0.05$) en el uso mensual de los hábitats. *Vocablo importante*: el guazuncho pardo; *Mazama gouazoubira*; uso del habitat; Argentina.

The brown brocket deer is a poorly known species inhabiting shrubby savannas and forests in South America. They occur east of the Andes and from Venezuela south to northern Argentina (Cabrera and Yepes, 1940). This small deer's social structure is based on family units (Olrog and Lucero, 1981) and it is among the largest herbivorous species in the Chaco Region (Bucher, 1980). The species is important to local economies because it provides meat for aboriginal people and according to Ojeda and Mares (1982), brocket pelts are traded in considerable quantities.

The brown brocket deer is one of three species of cervids, together with the red brocket deer (*Mazama americana*) and the marsh deer (*Odocoileus dichotomus*), occurring at El Bagual Ecological Reserve (Yanosky, 1989). Microhabitat preferences appear to separate them (Yanosky, 1989, 1991), the red brocket being found in non-native *Eucalyptus* forests and the marsh deer in "bañados" (flooded grasslands). These species are completely segregated by habitat. Furthermore, the tracks of the three species are easily distinguished with no possibility of track misidentification. No information on seasonal habitat use of brown brockets has been reported. We are the first to have monitored habitat use of this brocket throughout the year at El Bagual Ecological Reserve.

The estimation of wild animal population parameters by sign counts has been widely used, especially for deer (Caughley, 1977; Davis and Winstead, 1980; Tellería, 1986). Ockenfels and Bissonette (1983) developed a track plot system to monitor habitat use and seasonal activity levels in white-tailed deer (Ockenfels and Bissonette, (1982). We applied this same method for the brown brocket deer at El Bagual Ecological Reserve.

Materials and Methods

El Bagual Ecological Reserve is a 3,462 hectare protected area located in the Chaco Biogeographical Region of northeastern Argentina (Formosa province). The Chaco is an area comprising grasslands and forests, with equilibrium maintained by floods and fires (Morello and Adamoli, 1974). El Bagual includes bañados with sparse woods composed of different plant structure and species. These woods can be classified according to seral stages and have been reported elsewhere (Yanosky and Mercolli, 1993).

The brown brocket deer uses all woody areas at El Bagual: shrubby savannas, early seral stage or forest under formation, low forest and high forest or subtropical jungle (Yanosky and Mercolli, 1989, 1991). These four plant communities are characterized by both herbaceous strata and arboreal elements. The herbaceous stratum is important in the shrubby savannas, but less so in the high forest where the ground is totally dominated by bromeliads that make access difficult. Forest elements are not important features in the shrubby savannas, but are increasingly dominant in the other communities up to high forest, where trees are more than 20 meters high and little sunlight reaches the ground.

Study sites were selected on game trails in each plant community where 14 round plots 3 m^2 were established in exposed areas. Plots were located on a straight, randomly oriented transect through each habitat type, spaced 100 meters apart and established by disturbing the soil with an axe, then raking the soil and litter up to 10 centimeters deep. Each plot was then swept with a metallic broom so that all tracks would be detected. Track sets indicated that deer passed through the plots in random directions. It was impossible to distinguish separate sets of tracks left by different individuals, so a single hoof impression was considered as one track and all the plots (56) were "read" periodically between December 1988 and November 1989. Efforts were made to read each plot weekly, but heavy rains prohibited this because they frequently erased the track record between sampling visits. We utilized each heavy rain period to initiate a new sampling period. After reading each plot, the plots were swept with the metallic broom leaving the plot prepared for the next sampling.

Data collected from the plots included a count of the total number of deer tracks. An activity index, the number of tracks/day (= NTD), was calculated according to the methodology developed by Ockenfels and Bissonette (1983). NTD indexes were calculated by dividing the total tracks counted in all plots by the number of days in each sampling period and number of plots with or without tracks. We assumed that these values were related to general levels of brocket deer activity, although it is not known if brockets are territorial with discrete home ranges.

Monthly NTD means, seasonal NTD means, and NTD means for each cover type were calculated. Bartlett's test and ANOVA were used for data analysis (Sokal and Rohlf, 1981).

Results and Discussion

Each sample plot was read 44 times, for a total of 2,464 samples. Each of the habitat types was represented by the same number of

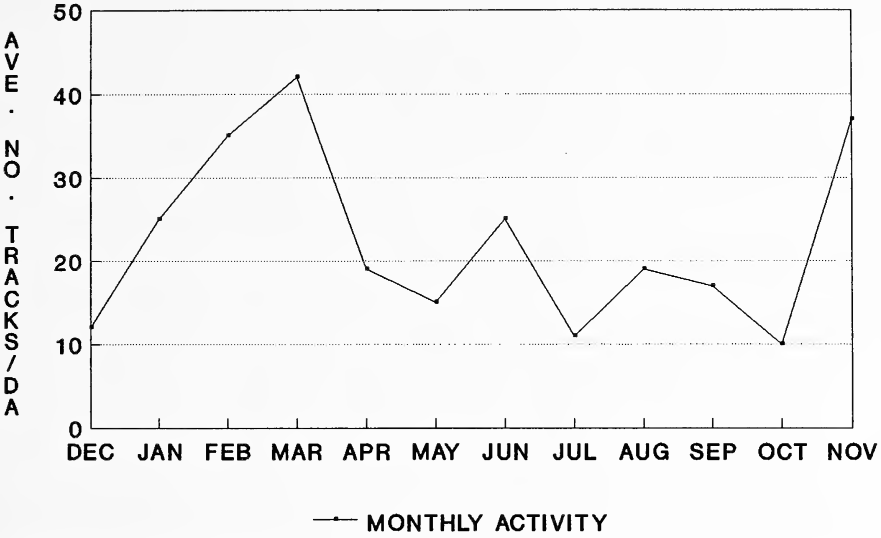

FIGURE 1. Activity levels (sums of USO indices by cover types) of brown brocket deer on four plant associations within the El Bagual Ecological Reserve, Argentina, from December 1989 to November 1990. Data represented by number of tracks counted/day for 56 plots for this figure and Figures 2 and 3.

readings. A generalized pattern for the period December 1988-November 1989 is shown in Fig. 1.

Six hundred eighty-nine (28%) of the 2,464 samples contained deer tracks. A total of 5,283 tracks was counted during the period of 984 days: 240 days from the forest under formation, 249 from the shrubby savanna, 249 from the high forest, and 246 from the low forest.

We analyzed the data for differences among habitat use levels. Bartlett's test indicated variances were similar and homogeneous in the four habitat types studied ($X^2_{(3)} = 5.23$, $P>0.1$), so ANOVA was used to test for differences among means. NTD means from the four habitat types were not significantly different, that is, the four habitat types did not differ in average use by brocket deer throughout the year $F_{(3,44)} = 2.55$, $P>0.05$).

Monthly differences in NTD for forest under formation and shrubby savannas showed the same unimodal behavior with an increase in activity during late summer (Fig. 2). The same parameter is shown in Fig. 3 for high and low forest. Patterns of seasonal occupancy of these two cover types were similar with more homogeneous NTDs throughout the year, but with an increase during late spring. ANOVA was used to test for monthly differences in mean habitat use levels, and nonsignificant differences were recorded for monthly uses ($F_{(11,36)} = 1.99$, $P>0.05$).

Seasonal activity levels were obtained for each cover type. Data

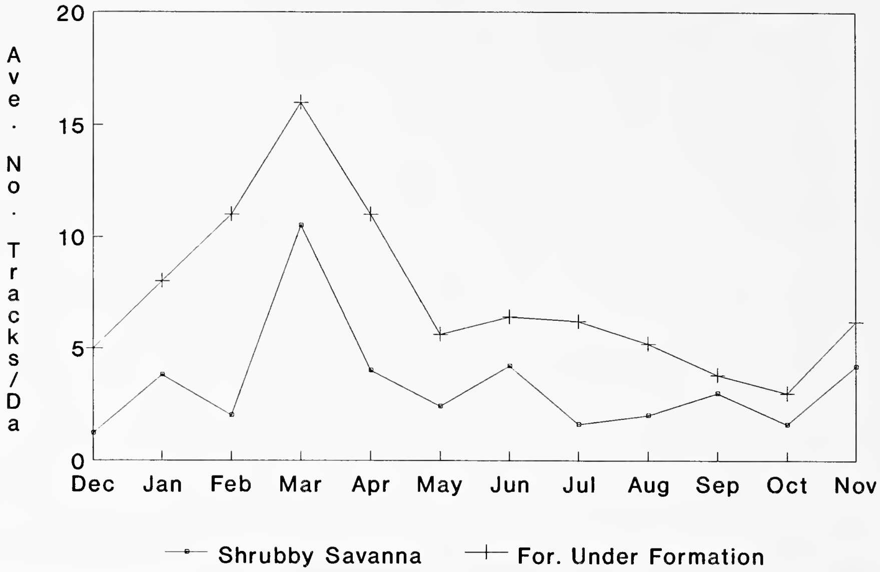

FIGURE 2. Activity levels of brown brocket deer for two cover types (arbustive savanna and forest in formation) at El Bagual Ecological Reserve, Argentina.

suggest a proportionately greater use of early successional forest during spring, although ANOVA indicated that habitat use was not significantly different according to seasonal NTDs ($F_{(3,12)} = 1.42$, $P>0.25$).

Although the generalized pattern represented in Fig. 1 shows activity peaks during late summer-early autumn, early and late winter, and late spring, these trends were not statistically significant. Brocket deer appeared to use the four available forest communities to the same extent. These four communities are approximately equally represented in the study area. No preference for any one of these communities was detected in relation to availability.

The brown brocket deer has been extirpated in some regions of its distribution, but its species survival status is somewhat more stable when compared with other species of *Mazama* because of its wide distribution in South America (Palermo, 1983). Knowledge of population parameters, seasonal activity and habitat use is required to provide management guidelines for this declining species. We hope that the information herein will prove useful for the management of this species in other parts of its range.

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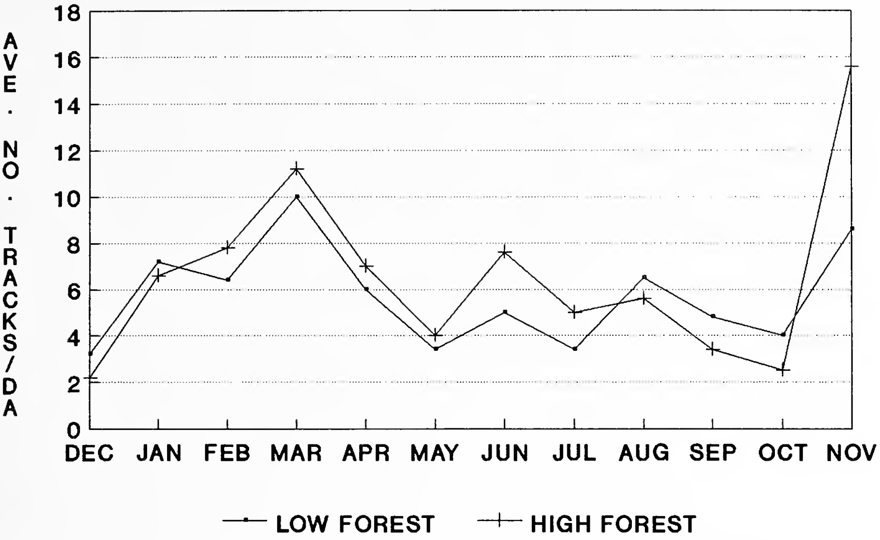

FIGURE 3. Activity levels of brown brocket deer for two cover types (high forest and low forest) at El Bagual Ecological Reserve, Argentina.

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PRODUCTION OF PECTINASES BY *EXSEROHILUM ROSTRATUM*

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Abstract.—The effect of different carbon sources on the production of extracellular pectinases of *Exserohilum rostratum* was investigated. Production of polygalacturonase and pectinesterase was induced by sodium polypectate and pectin. Production of these enzymes was repressed or completely inhibited in the control cultures containing galacturonic acid as carbon source and enzyme inducer. Maximum production of polygalacturonase was induced when sodium polypectate or pectin was used as a carbon source. Highest production of pectinesterase was induced by pectin. The results indicate that the pectic enzymes of *E. rostratum* may be produced in sequence, i.e. the production of polygalacturonase is followed by pectinesterase. *Key words*: *Exserohilum*; pectinase; polygalacturonase; pectinesterase.

Direct penetration of susceptible hosts by the infective hyphae of phytopathogenic fungi is facilitated by the production of cutinases (Agrios, 1988). Penetration of the host is followed by disintegration of the pectic substances of the middle lamella and the primary cell wall by pectolytic enzymes (Kenaga, 1974; Agrios, 1988). Production of pectolytic enzymes is induced in plant pathogenic fungi when these organisms are grown on media containing various carbon sources and enzyme inducers. These carbon sources include sugar polymers (Cooper and Wood, 1973), sodium polypectate and pectin (Pegg, 1981; Alana et al., 1989) and sugar beet cell walls (Bugbee, 1990).

Exserohilum rostratum (Dreschler) Leonard & Suggs (Leonard and Suggs, 1974), attacks many gramineous species of plants, including some hosts of economic importance. *E. rostratum* causes foliage blight of sugar cane seedlings (Byther and Steiner, 1972), leaf disease of corn (Cook, 1981), stalk rot of corn (Kucharek, 1973; Nyvall, 1989) and leaf blight of sorghum (Sprague, 1950). The main objectives of this work were to: identify the pectin degrading enzymes of *E. rostratum* and determine the effects of the carbon source on the production of these enzymes by the test fungus.

Materials and Methods

Organism and culture conditions

Stock cultures of *E. rostratum* were maintained on PDA slants (Difco, B13). The fungus was previously grown in 250-milliliter flasks with 125 milliliters of a medium containing: 0.02 percent $MgSO_4.7H_2O$, 0.01 percent $Ca(NO_3)_2.4H_2O$, 0.1 percent Peptone, 0.2 percent yeast extracts, 2.0 percent glucose in Na-citrate buffer at pH 4.8. After four days growth at 26°C, five milliliters of mycelium inoculum was washed twice in distilled water and transferred to the cellulolytic growth medium. The medium for the production of pectinases contained: 0.15 percent NH_4NO_3, 0.24 percent K_2PO_4, 0.08

percent $MgSO_4$, 0.08 percent $Ca(NO_3)_2.4H_2O$, 0.72 ppm Fe $(NO_3)_3.9H_2O$, 0.44 ppm $ZnSO_4.7H_2O$, 2.0 ppm $MnSO_4.4H_2O$, 0.40 ppm $ZnCl_2$, 0.1 percent Peptone, 0.1 percent yeast extract, and 1.0 percent carbohydrate. The carbohydrates (Sigma Chemical Company) used as carbon sources and enzyme inducers included: sodium polypectate and apple pectin. The control cultures had galacturonic acid (Sigma Chemical Company) as carbon source. The pH of the growing medium was adjusted to 4.8 with citric acid. Incubation of the cultures was carried out for four days in covered 250-milliliters flasks on an orbital shaker at 100 rpm at 26°C.

Enzyme preparation and assays

Culture fluids were collected at intervals of 24, 48, 72, and 96 hours after transferring the inoculum to the growing medium. The culture fluids were centrifuged (4,500 rpm, 30 minutes, 10°C) to obtain a clear supernatant. The supernatant was subsequently used for the determination of extracellular enzyme activity. For simplification, the collected supernatant is hereafter referred to as the enzyme. All tests were replicated four times.

Polygalacturonase (Pectinase, EC 3.2.1.15)

Polygalacturonase activity was measured by combining one milliliter of enzyme with five milligrams of sodium polypectate in one milliliter of 0.05 M sodium citrate buffer (pH 4.8) and incubating the reaction mixture for 30 minutes at 40°C. The tubes were stirred once during incubation. After centrifugation, the concentration of galacturonic acid or its reducing sugar equivalent in the supernatant was determined by the dinitrosalicylic acid method of Miller (1959).

Pectinesterase (Pectin methylesterase, EC 3.1.1.11)

Pectinesterase activity was measured by combining one milliliter of enzyme with five milligrams of pectin in one milliliter of 0.05 M sodium citrate buffer (pH 4.8). The reaction mixture was incubated at 40°C for 30 minutes. After centrifugation, the concentration of galacturonic acid or its reducing sugar equivalent in the reaction mixture was measured by the dinitrosalicylic acid method of Miller (1959).

Protein determination

Extracellular protein in the crude supernatant was determined with the BCA reagent (Pierce Chemical Company) using bovine serum albumin as standard.

Data analysis

All enzyme activity tests and protein determinations were replicated four times. Enzyme activities were expressed as units of specific enzyme activity and represent means plus or minus the standard deviation of four replications. Each unit of enzyme specific activity was calculated as the amount of enzyme that liberated one micromole of galacturonic acid (or its reducing sugar equivalent) per minute per milligram of protein under the assay's conditions.

RESULTS

Growth and total protein

The development of the test fungus (expressed in grams per liter of mycelium dry weight) declined after 72 hours of growth in cultures containing sodium polypectate, pectin or galacturonic acid as carbon sources (Fig. 1a,b,c). Cultures containing sodium polypectate accumulated maximum concentrations of protein (7.26 mg/ml) after 48

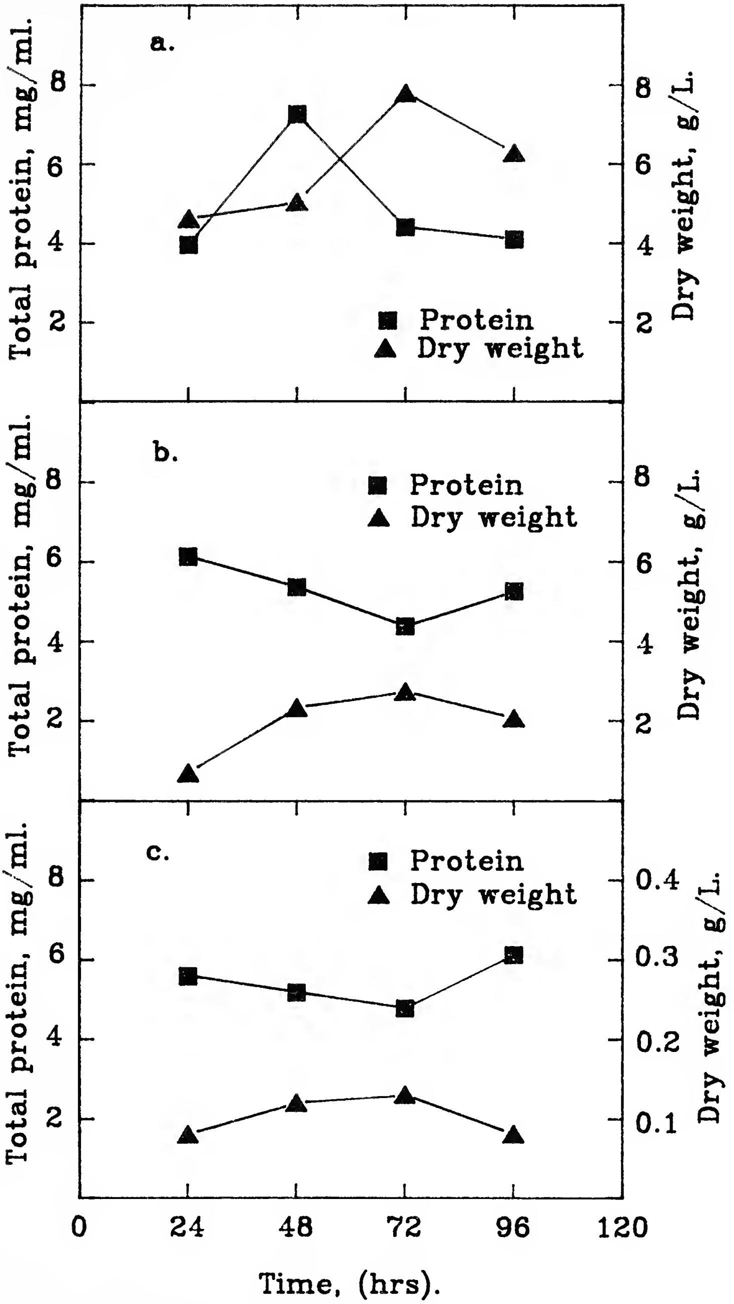

FIGURE 1. Growth and production of total extracellular protein by *E. rostratum* cultivated in liquid media with different carbon sources: a. sodium polypectate, b. pectin, and c. galacturonic acid.

Table 1. Effect of three carbon sources on the production[1] of polygalacturonase by *Exserohilum rostratum*.

	Hours of growth in liquid medium			
Carbon source	24	48	72	96
Sodium polypectate	1.33±0.02	6.19±0.11	12.79±0.22	31.02±0.18
Pectin	0.79±0.01	9.21±0.16	11.30±0.20	28.77±0.78
Galacturonic acid	ND	ND	ND	ND

[1] U/min/mg of protein. Mean ± SD of four replications.
ND, no enzyme activity detected.

hours of growth (Fig. 1a). Cultures containing pectin as the carbon source accumulated 6.13 mg/ml of total protein after 24 hours of growth in the culture medium (Fig. 1b). This concentration of extracellular protein declined after 48 and 72 hours (5.35 and 4.36 mg/ml, respectively). In these cultures, total extracellular protein determined after 96 hours of growth was 5.25 mg/ml (Fig. 1b). Maximum concentration of extracellular protein (6.12mg/ml) accumulated in the fluids of cultures containing galacturonic acid after 96 hours of growth (Fig. 1c).

Polygalacturonase

Production of polygalacturonase was induced in cultures containing sodium polypectate or pectin as carbon source and enzyme inducer. No polygalacturonase activity was detected in fluids of the control cultures with galacturonic acid as carbon source (Table 1). Increments in specific polygalacturonase activity measured in fluids obtained from cultures containing sodium polypectate or pectin as carbon source are shown in Figure 2. The accumulation of extracellular proteins declined after 48 hours of fungal growth in cultures with sodium polypectate (Fig. 2a). In cultures with pectin as the carbon source, the concentration of extracellular protein declined after 24 hours of growth (Fig. 2b). Maximum activities of this enzyme (31.02 and 28.77 U, respectively) were measured after 96 hours of growth in the liquid medium (Table 1).

Pectinesterase

Production of pectinesterase was induced in cultures containing sodium polypectate or pectin as carbon source. Maximum pectinesterase specific activity (19.77 U) was measured in fluids harvested after 48 hours of fungal growth in cultures with sodium polypectate (Table 2). This activity was more than twice the pectinesterase activity (8.84 U) measured in fluids collected after 96 hours of growth from cultures where pectin was the carbon source

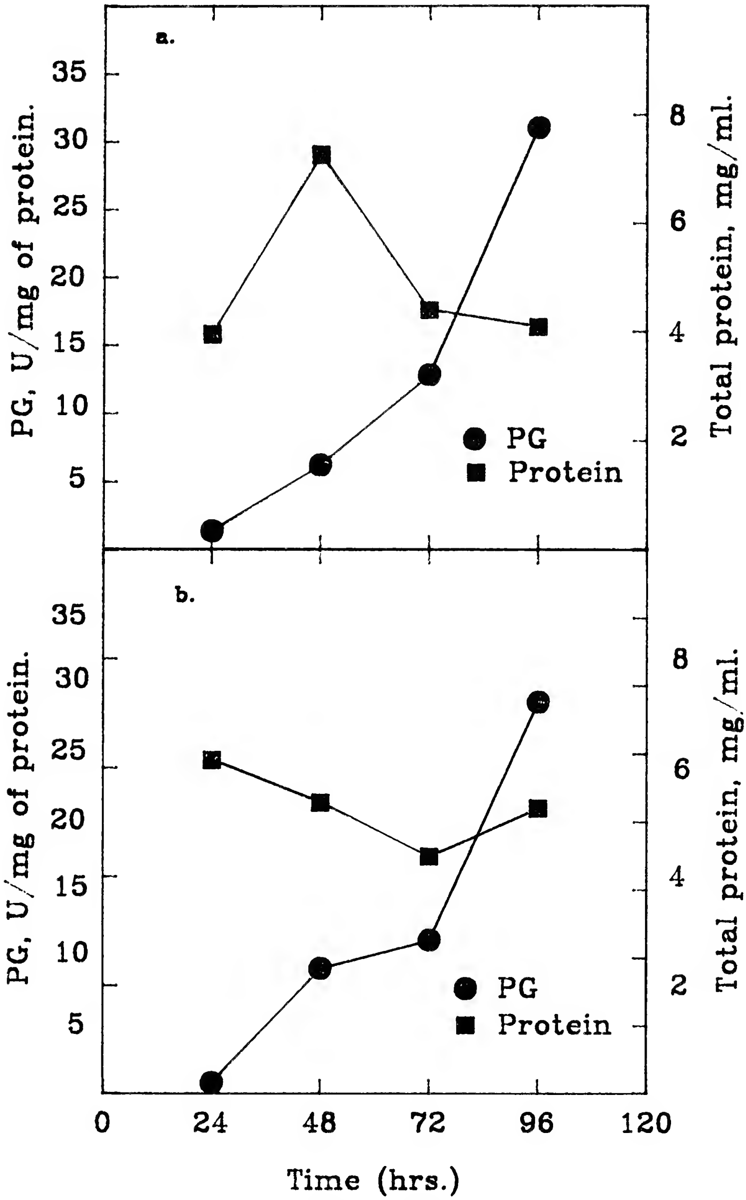

FIGURE 2. Specific activities of polygalacturonase (PG) produced by *E. rostratum* grown in media with sodium polypectate (a) and pectin (b).

TABLE 2. Effect of three carbon sources on the production[1] of pectinesterase by *Exserohilum rostratum.*

	Hours of growth in liquid medium			
Carbon source	24	48	72	96
Sodium polypectate	0.69±0.24	19.77±0.67	10.06±0.38	6.60±0.17
Pectin	0.30±0.03	6.80±0.17	7.50±0.05	8.84±0.06
Galacturonic acid	ND	ND	ND	ND

[1] U/min/mg of protein. Mean ± SD of four replications.
ND, no enzyme activity detected.

(Table 2). No pectinesterase activity was detected in fluids of the control cultures with galacturonic acid as carbon source (Table 2).

DISCUSSION

Polygalacturonase and pectinesterase were induced in cultures of *E. rostratum* containing sodium polypectate or pectin as the carbon source. Production of both enzymes by the test fungus was repressed or completely inhibited when the liquid cultures contained galacturonic acid as the carbon source. It has been shown in similar studies that plant pathogenic fungi can be induced to produce polygalacturonase and pectinesterase when grown in liquid media with the appropriate carbon source (Cleveland and McCormick, 1987; Cooper and Wood, 1973; Crawford and Kolattukudy, 1987; De Lorenzo et al., 1987). Repression of the induction of polygalacturonase and other pectic enzymes by galacturonic acid or glucose used as carbon sources has been shown in other studies of phytopathogenic fungi (De Lorenzo et al., 1987; Leone and Van Den Heuvel, 1987).

The pectic enzymes of *E. rostratum* were produced almost simultaneously. Both enzymes, polygalacturonase and pectinesterase were detected in culture fluids of the fungus collected after 24 hours of growth. However, the activity of polygalacturonase was two times higher than the activity of pectinesterase. The activity of polygalacturonase may be an indication that the two enzymes are produced in sequence, the synthesis of polygalacturonase followed by that of pectinesterase. The activity of polygalacturonase increased steadily in the culture fluids collected after 24 to 96 hours of growth in the medium. Maximum activity of pectinesterase was measured in fluids collected after 48 hours of fungal growth. The production in sequence of pectic enzymes has been demonstrated in similar studies of plant pathogenic fungi (Bahkali, 1987; Leone and Van Den Heuvel, 1987). In these studies, polygalacturonase was detected first in the culture filtrates and was followed by pectinesterase.

The ability of some plant parasitic fungi to produce extracellular pectinases in culture has been related to their pathogenic activities (Cleveland and McCormick, 1987; Crawford and Kolattukudy, 1987; Reyes et al., 1988). Hershenhorn et al. (1989) found that the production of polygalacturonase was higher in virulent strains of *Geotrichum candidum* than in avirulent strains of the same fungus. It was also reported (Hershenhorn et al., 1989) that the polygalacturonase of the virulent strain was more effective than the avirulent in causing maceration of the white tissue of lemon peel. Kim and Lee (1988) found that strongly pathogenic isolates of *Alternaria mali* showed higher pectolytic enzyme activity than weakly pathogenic isolates of the same fungus. The high polygalacturonase and pectinesterase activities of *E. rostratum* found in this study suggest that these enzymes are involved in its pathogenicity.

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GENERAL NOTES

A NOTE ON NORMAL SPACES

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The T_4 axiom was introduced in 1923. The space (X, T) is normal if for disjoint closed sets A and B, there exist disjoint open sets U and V such that $A \subset U$ and $B \subset V$. A normal T_1 space is called a T_4 space (Tietze, 1923). Normal spaces have proven to be important and useful spaces and have been continually studied through the years. In 1925, Urysohn made a substantial contribution in the study of normal spaces with his lemma: The space (X,T) is normal if and only if for nonempty disjoint closed sets A and B, there exists a continuous function $f : (X,T) \rightarrow ([0, 1], S)$ such that $f(A) = 0$ and $f(B) = 1$, where S is the usual relative metric topology on [0, 1] (Urysohn,1925).

In 1963 semi open sets were introduced. Let (X,T) be a space and let $A, B \subset X$. Then A is semi open if there exists $O \in T$ such that $O \subset A \subset Cl(O)$(Levine, 1963). Since their introduction, semi open sets have been used to define and investigate many properties of topological spaces, including semi closed sets, which were used to define the semi closure operator. The subset A is semi closed if $X \setminus A$ is semi open and the semi closure of B, denoted by $sclB$, is the intersection of all semi closed sets containing B(Crossley,1971). Crossley (1971) used the semi closure operator to show that there is a finest topology $F(T)$ in the class of topologies on X having the same semi open sets as (X,T). Like semi open sets, semi closed sets and the semi closure operator have been used to define and investigate many properties of spaces. One such application is exhibited in the introduction of feebly open sets. The subset A is feebly open, denoted by $A \in FO(X,T)$, if there exists $O \in T$ such that $O \subset A \subset sclO$ (Maheshwari et al.,1978). The further investigation of feebly open sets showed, in fact, that $FO(X,T) = F(T)$ (Dorsett,1985). The investigation of feebly open sets and related properties has led to a better understanding and new characterizations of long-studied, well-known properties (Dorsett,1987; 1989). Below are new characterizations of normal spaces, which were discovered during the study of feebly open sets and related properties.

Theorem: Let (X,T) be a topological space. Then, the following are equivalent: (a) (X,T) is normal, (b) for each nonempty closed set C and each open set O such that $C \subset O$ and $\phi \neq Fr(O) \subset X \setminus C$, there exists a continuous function $f : (X,T) \rightarrow ([0, 1],S)$ such that $f(C) = 0$ and $f(Fr(O)) = 1$, and (c) for each closed set C and each open set O such that $C \subset O$ and $C \cap Fr(O) = \phi$, there exist disjoint open sets U and V such that $C \subset U$ and $Fr(O) \subset V$.

Proof: (a) implies (b): Let C be a closed set and let $O \in T$ such that $C \subset O$ and $\phi \neq Fr(O) \subset X \setminus C$. Then C and $Fr(O)$ are disjoint closed sets and by Urysohn's lemma, there exists a continuous function $f : (X,T) \rightarrow ([0, 1],S)$ such that $f(C) = 0$ and $f(Fr(O)) = 1$.

(b) implies (c): Let C be a closed set and let $O \in T$ such that $C \subset O$ and $C \cap Fr(O) = \phi$. If one or both of C and $Fr(O)$ is empty, then ϕ and X can be used to separate C and $Fr(O)$. Thus, consider the case that both C and $Fr(O)$ are nonempty. Let $f : (X,T) \rightarrow ([0, 1],S)$ be continuous such that $f(C) = 0$ and $f(Fr(O)) = 1$. Then $f^{-1}([0, .5))$ and $f^{-1}((.5, 1])$ are disjoint open sets containing C and $Fr(O)$, respectively.

(c) implies (a): Let A and B be disjoint closed sets. If one of A and B is open, then the closed, open set and its complement can be used to separate A and B. Thus, consider the case that neither A nor B is open. Then, $A \subset Ext(B) \in T$, $Fr(Ext(B)) \neq \phi$ and $A \cap Fr(Ext(B)) = \phi$. Let U and V be disjoint open sets such that $A \subset U$ and $Fr(Ext(B)) \subset V$. Then, A

$\subset W = U \cap Ext(B) \in T$, $Cl(W) \subset Cl(Ext(B))$, and $Fr(Ext(\mathrm{B})) \cap Cl(W) = \phi$, which implies $Cl(W) \subset Ext(B)$ and W and $X \setminus Cl(W)$ are disjoint open sets containing A and B, respectively.

Of course, as known earlier, there is nothing magical about the real numbers 0 and 1 and the results above can be combined with a well-known technique to obtain the following additional characterization of normal spaces: for each nonempty closed set C and each open set O such that $C \subset O$ and $\phi \neq Fr(O) \subset X \setminus C$, and for distinct real numbers a and b, there exists a continuous real valued function f defined on (X,T) such that $f(A) = a$ and $f(Fr(O)) = b$.

It is rewarding and stimulating that, after years of productive study, additional properties of classical topological properties continue to be discovered, and, as in this case, the avenue of discovery of these additional properties may not be down a familiar path.

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A SMALL COLLECTION OF EARLY HEMPHILLIAN AMPHIBIANS AND REPTILES FROM SOUTHWESTERN NEBRASKA

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Early Hemphillian Land Mammal Age (late Miocene) amphibians and reptiles are so poorly known in North America that a small collection of amphibians and reptiles from the early Hemphillian Potter Quarry (ca. 8 million years before the present) of Cheyenne County, Nebraska, is noteworthy. The Potter Quarry (University of Nebraska State Museum locality Cn 106B) is in sec. 7, T13N, R51W, approximately 12 kilometers Southeast of Scottsbluff. The fauna comes from the middle of a shallow section of the Ogallala Group (Ash Hollow Formation) located on a divide of a major paleovalley of the Ash Hollow rocks (Breyer, 1981). Large mammals of the fauna have been reported by Breyer (1981), and here I add one salamander, one frog, and two snakes to the faunal list.

Ambystoma maculatum Group; cf. *A. maculatum.*—2 vertebrae (UNSM 96455). Tihen (1958) divided the genus *Ambystoma* into subgenera and species groups based (partly) on osteological characters. The fossil vertebrae are assigned to the *A. maculatum* group based on their elongate shape, and having postzygapophyses extending posteriorly past the neural arches. The *A. maculatum* group includes the living species *A. maculatum, A. gracile, A.*

jeffersonianum, A. laterale, A. macrodactylum, and the small Miocene species *A. minshalli* Tihen and Chantell and *A. priscum* Holman. The Potter Quarry vertebrae represent large adult individuals that agree best in size and vertebral characters with *A. maculatum*, but because of the amount of vertebral variation within the group, identification to species is uncertain.

Rana sp. indet.—3 humeri (UNSM 96444). These bones are identical to those of living *Rana*, but ranid humeri are not diagnostic to species.

Thamnophis sp. indet.—12 vertebrae (UNSM 96447). These fossils are identified as *Thamnophis* rather than *Nerodia, Regina*, or the extinct genus *Neonatrix* based on their relatively small size, elongate shape (Brattstrom, 1967), and moderately short (but much longer than those of *Neonatrix*), posteriorly directed hypapophyses. The vertebrae are similar in size and appearance to several Recent forms of *Thamnophis*.

Paleoheterodon tiheni Holman—2 trunk vertebrae (UNSM 96446). This snake represents the only extinct reptile from the Potter Quarry. The vertebrae are distinguished from living *Heterodon* based on their more vaulted neural arches (Holman, 1977). Moreover, I can find no trenchant differences between the fossils and those of the only known North American species of the genus, *P. tiheni*.

Little paleoenvironmental information is offered by the small Potter Quarry collection of amphibians and reptiles. But, the presence of *Ambystoma maculatum, Rana* sp., and *Thamnophis* indicates that a permanent body of water was present. *Paleoheterodon tiheni* was probably there to prey on the anurans associated with the aquatic habitat.

I am grateful to Michael Voorhies (University of Nebraska State Museum) for bringing the fossils to my attention, and for allowing me to study them.

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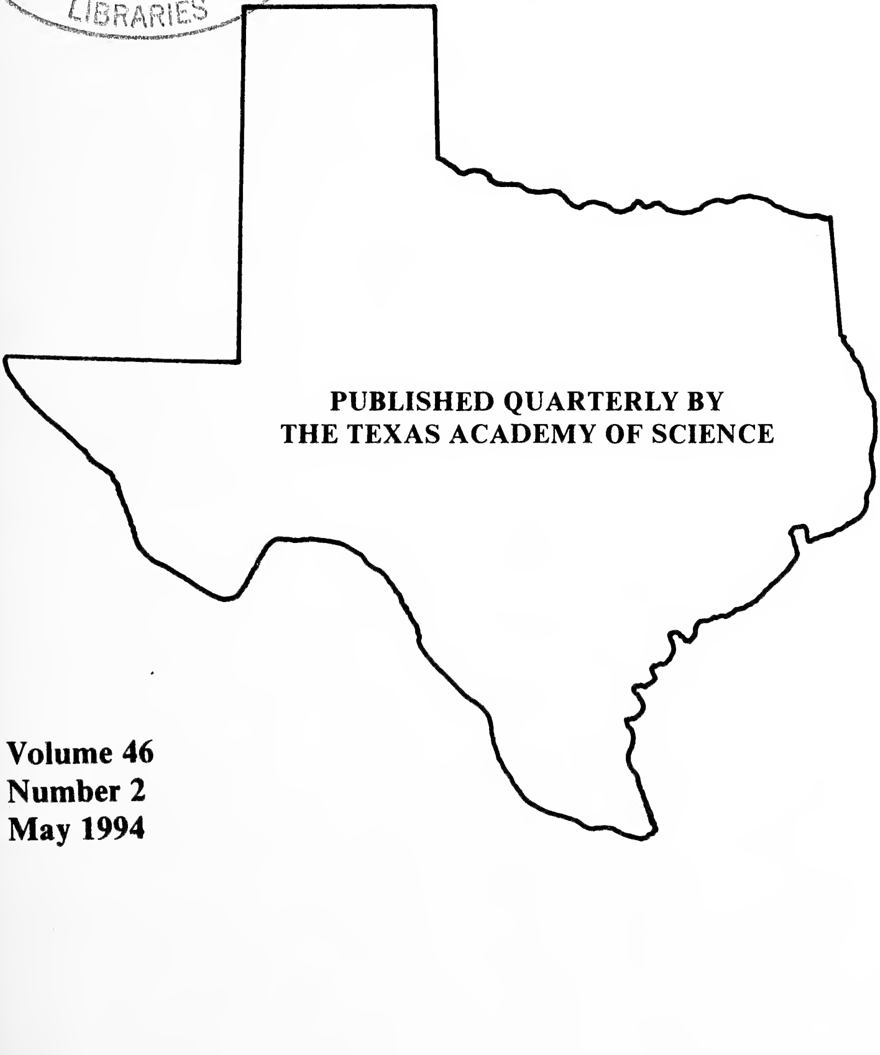

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THE TEXAS JOURNAL OF SCIENCE

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THE CURRENT STATUS AND FUTURE PROSPECTS OF THE TEXAS HORNED LIZARD (*PHRYNOSOMA CORNUTUM*) IN TEXAS

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Abstract.—A survey to assess the status of the Texas horned lizard (*Phrynosoma cornutum*) in Texas was conducted in 1992. Museum specimen records were compiled to assess historical distribution and abundance, and 100 sites across the state with adequate historical records were selected to be surveyed for current presence and abundance of the species. Interviews were conducted with local residents concerning potential correlative factors to horned lizard occurrence, and an extensive database compiled from two sighting surveys distributed statewide was also used for the same purpose. Horned lizards, or evidence of their occurrence, were detected at 48 of the survey sites. These results are discussed in relation to current and historic land-use, pesticide use, and the invasion of the Red Imported Fire Ant (*Solenopsis invicta*). The future of the Texas horned lizard as a component of the natural heritage of the state is discussed. *Phrynosoma cornutum* serves as an excellent indicator of the general environmental health of terrestrial ecosystems in Texas. *Key words*: horned lizards; *Phrynosoma cornutum*; conservation; fire ants; surveys; Texas.

The Texas horned lizard (*Phrynosoma cornutum*) is a familiar component of the fauna of Texas, and was officially designated the state reptile by the Texas Legislature in 1993. Historically, the species' range included the entire state of Texas except for the easternmost counties which constitute the Piney Woods (LBJ School of Public Affairs, 1978). These lizards are dietary specialists on harvester ants of the genus *Pogonomyrmex* (Whitford and Bryant, 1979), which constitute up to 69% of an individual lizard's diet (Pianka and Parker, 1975). *P. cornutum* adults must utilize several colonies of harvester ants in one day to meet metabolic energy requirements (Munger, 1984). They also feed opportunistically on a variety of other arthropods including grasshoppers, isopods, beetles and beetle larvae (Davis, 1941; Pianka and Parker, 1975; Cohen and Cohen, 1990). Because the species is a specialized insectivore and occurs statewide in a variety of ecotypes, it may serve as an indicator of the general environmental health of terrestrial habitats in Texas: another "canary in the coal mine" (Eldredge, 1991).

Phrynosoma cornutum is listed as a threatened species in Texas and a Federal category 2 candidate species. It was one of the first animals listed by Texas as threatened, on 18 July 1977 (Texas Parks and Wildlife Code, 1987). Ten years prior to the state's adoption of

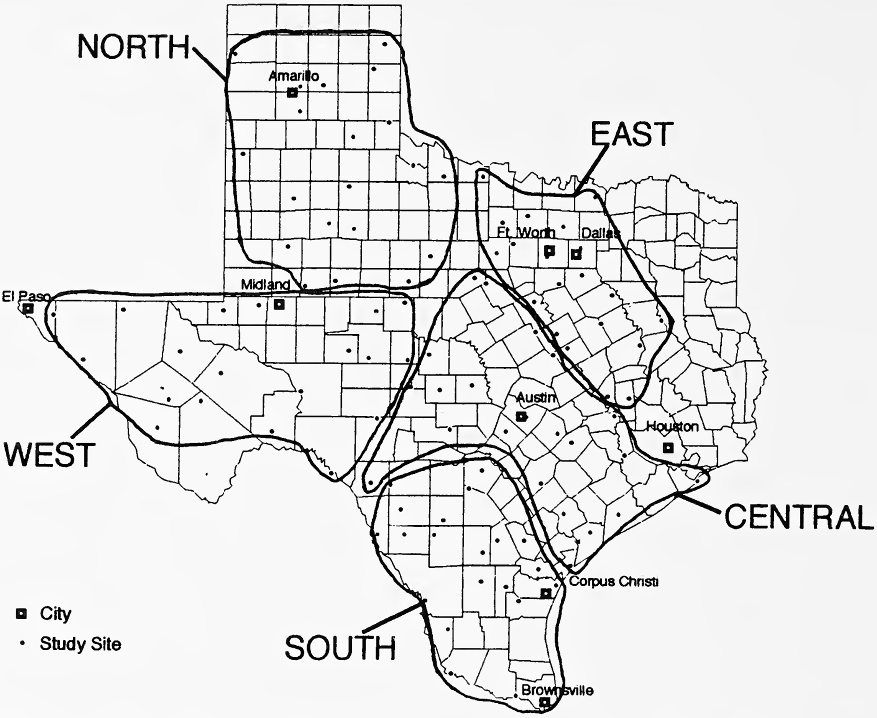

FIGURE 1. Map of Texas indicating the areas surveyed for Texas horned lizards in 1992. Dots indicate specific survey sites. The ellipses delineate the regions used in analyses.

protective legislation for threatened species, *P. cornutum* was protected from commercial collection by separate legislation (Bigony, 1981; Welch, 1993; J. Christie, pers. comm.). This protection was originally sought for *P. cornutum* for reasons including over-collection of specimens for the pet trade, exportation by Boy Scouts who traded them at national jamborees, and utilization in the curio trade. Recently, concern was focused on the status of *Phrynosoma cornutum* in Texas (Price, 1990). Anecdotal information indicated *P. cornutum* had disappeared east of a line extending from Fort Worth to Corpus Christi (Fig. 1) except for a few isolated and introduced populations, and had become rare and localized in other parts of the state. Three primary reasons have been suggested for the decline: habitat alteration or destruction by agriculture and urbanization, use of insecticides and other toxic chemicals on crops and to control *Solenopsis invicta* (the red imported fire ant), and other direct or indirect effects incurred with the invasion of *Solenopsis invicta* (Price, 1990). We report here the results of a study designed to assess (1) the historical distribution and abundance of *P. cornutum* in Texas, (2) the current distribution and abundance of *P. cornutum* in Texas, and (3) the potential factors implicated in the reported decline of this species.

METHODS

Museum Collection Records

Museum collection records of *P. cornutum* through 1987 were acquired by surveying institutions listed in Edwards (1975) and others, supplemented with additional records from West Texas State University that included records to 1989. Records from the scientific literature were also collected as well as records from biologists across the state. Ten maps were constructed using Atlas Mapmaker, Version 3.51 showing the number of lizards collected in each county during each decade, with records predating this century included together in one figure (Donaldson et al., 1993).

Sighting Survey

Texans are generally familiar with *Phrynosoma cornutum* through childhood or current experiences. We considered this collective knowledge to be a valuable untapped resource concerning the status of this species in Texas. Two separate sighting surveys were distributed in an attempt to utilize this resource and obtain broad based information on the current and historical abundance of the species; see Donaldson et al. (1993) for details. Survey A was initiated in the spring of 1991 when 30 central Texas newspapers, as well as interested individuals, were sent survey forms as a pilot test. In August 1992, *Texas Parks and Wildlife Magazine* also published the sighting survey (Goin, 1992). In the first section of the survey, the question was asked, "Have you seen a horny toad in the last 10 years?". In the second section, the question "Did you used to see horny toads often?" was asked. Additional information was requested in the event of a positive answer to either question. Thus, individuals could provide information on current and historical sightings of *P. cornutum*.

Survey B was initiated in the summer of 1992 to accompany the field work (see below). This survey was more limited in scope than the previous survey in that respondents were only queried as to the details of current sightings of *P. cornutum*. The survey form and a press release were mailed to newspapers published in the counties where field surveys were conducted. Thirty-one of the 197 newspapers which were sent the mailing elected to publish the survey in its original form. In addition, one newspaper published an article on the plight of the Texas horned lizard in which a request was made that sightings of the lizard be reported to us. This article was subsequently picked up by the Associated Press and appeared as an AP wire release in at least five newspapers across Texas. Responses to this article are included in the data analyzed here as they represent a substantial fraction of the responses received in regard to current sightings of *P. cornutum*.

Data tabulated from survey A included date, time and county of sighting, number and sizes of lizards sighted, comments, and county of origin of the response. Data tabulated from survey B included date, time, county, exact locality, description of area, weather conditions, number and sizes of lizards, behavior of lizards, and additional comments. County by county statistics regarding numbers of sightings of *P. cornutum* were compiled. Comments concerning the following categories were noted and tabulated: blood-squirting behavior, interactions with domestic animals, fire ants, harvester ants, land-use, interactions with other wildlife, pesticide use, resurgence in horned lizard populations, and horned lizard population trends. It should be noted that respondents were not prompted to make comments on these particular subjects. In each instance, an effort was made to focus on specific comments in the stated categories. For instance, general comments to the effect that the respondent believed pesticide use had contributed to the decline of horned lizard populations were shunned in favor of specific comments concerning applications of pesticides.

The survey responses were screened to eliminate any possibly erroneous sightings. For instance, sightings of "horned lizards" in excess of 10 inches in length were discounted as were sightings of "horned lizards" exhibiting uncharacteristic behaviors such as hopping or scurrying up trees. Sightings of horned lizards residing in "shoe boxes" or the like were not included unless the origin of the specimen could be reasonably ascertained. Sightings of dead horned lizards were included.

As the reporting of actual numbers of horned lizards sighted was often imprecise and qualitative, we decided not to attempt to compile those numbers. Instead, a positive response to query 1 or query 2 on survey A was counted as a single "current sighting" or "historical sighting", respectively, regardless of the number of lizards reported. One such "sighting" was recorded for each county in which the respondent reported seeing or having seen horned lizards. If the number of horned lizards seen and/or other comments by respondents indicated that horned lizards were common in a given county, then the corresponding "sightings" for that county were considered to be "abundant". Responses to survey B were analyzed in a similar manner.

The data from survey A were analyzed as the number of responses originating from counties in each region (#R), the number of current sightings of *P. cornutum* within each county during the period 1990-1992 (#CS), and the number of historical sightings within each county (#HS). Positive responses to query 1 in which a respondent indicated that their most recent sighting had occurred prior to 1990 were tabulated and are included in a county X decade X sighting matrix and displayed on maps (Table 3, Appendix 2 in Donaldson et al., 1993), but are not included in either #CS or #HS. The values of #CS and #HS can be greater than #R if respondents lived in a different county than where they observed *P. cornutum* and/or respondents observed *P. cornutum* in the same county(ies) over several decades.

When the value of at least one of the categories #R, #CS or #HS was 10 or greater within a given county, the following percentage was calculated:

$$\%D = [(\#HS - \#CS) \times 100] / \#HS$$

This percentage is a measure of the relative decline of *P. cornutum* for each of the five field survey regions.

The following numbers from survey B were tabulated for each county: the number of responses originating from that county (#R), the number of sightings within that county (#S), and the number of sightings within the county categorized as abundant (#A). The percentage of sightings categorized as abundant was also calculated when 10 or more sightings were reported within a given county.

Field Survey

Museum records were used to choose the target localities to be surveyed for current presence and abundance of *P. cornutum*. One hundred localities were chosen on the basis of having a good historical record of the occurrence of *P. cornutum*, and the specific survey localities matched the historical locations as closely as possible. The exact locations were expanded to include an area within an eight kilometer radius to insure access to property as close as possible to the historical locations. Localities were also limited to one site per county in an attempt to survey as much of the historical range of the species as possible.

The museum records, unfortunately, exhibit a paucity of localities in the Panhandle due to collection biases. Localities in the Panhandle, therefore, do not have an historical base comparable to the remainder of the state. Localities in the east Texas Piney Woods, such as in Nacogdoches County, were not included because *P. cornutum* populations there are believed to be introduced (Price, 1990). Alternate sites within the same counties as the preferred survey sites were identified in anticipation of problems obtaining access to private property. The alternate sites were chosen based on the same criteria as the preferred sites. Localities were then assigned to central, east, north, south, and west divisions of the state; 20 sites per area (Fig. 1) to minimize travel distances. All references to geographic divisions of Texas refer to these designated areas.

Field work was conducted between 25 May and 10 October 1992. Site identification numbers, counties surveyed, exact localities, survey dates, expected and observed habitat characteristics, current and historic land-use patterns, pesticide use, and additional information are in Donaldson et al. (1993) or are available from the authors. Field surveys were conducted using time-constrained search techniques (Campbell and Christman, 1982). Five biologists surveyed 20 sites each, and each site was to be surveyed three times between 25 May and 10 October 1992. Permission to access private property was obtained prior to surveying. Data recorded at each site included number of lizards, size (total body length and snout-to-vent length), sex, weight, behavior of individual *P. cornutum* encountered, photograph of individual lizards captured against color standards, toe-clip identification number, air and soil temperatures at point of capture, time of day, date, weather conditions and location of capture. Clipping was limited to one toe per foot, and clipped toes were retained and preserved in 95% ethanol for future genetic analysis. Additional information about each site was gathered including habitat characteristics, current and historic land-use practices, relative densities of *Solenopsis invicta* and *Pogonomyrmex* spp., and soil samples. Photographs of each locality were also taken. Two additional hours were spent at each site interviewing area residents about land-use and pesticide use.

RESULTS

Museum Collection Records

A total of 1,654 museum specimen records, representing 207 (81.5%) of Texas' 254 counties, were compiled for *P. cornutum*. The earliest record is from Galveston in 1862. These museum records represent a total of 3,262 individual lizards. The largest number of specimens collected was 1,077 from 151 counties in the decade 1960-1969. Of that number, 199 lizards were collected in Tom Green County alone. *P. cornutum* occurred historically throughout the state except for the far eastern counties, the latter not including counties along the Gulf Coast. *P. cornutum* does not appear in the far eastern counties prior to 1950, when the species was introduced to places like Nacogdoches. Counties from each designated survey region (Fig. 1) are represented in all decades (Donaldson et al., 1993), although the North Texas area has fewer counties represented. *P. cornutum* is well-represented from Trans-Pecos counties in all maps. South Texas counties, especially near Mexico, also show *P. cornutum* with a long and continuous history. *P. cornutum* was collected in Bexar and Travis counties prior to 1900 and up until 1979. It is difficult to observe population fluctuations from museum data because the locations and quantities of *P. cornutum* collected reflect subjective or opportunistic decisions of individual collectors. At first glance, *P. cornutum* appears to increase in Texas during the 1950's and 1960's. These decades, however, represent a time period during which Frank Blair and his students led an active herpetological program at the University of Texas at Austin which collected specimens across the state.

Some illustrative data are available, however, for a limited number of localities. For example, 115 *P. cornutum* were collected in 1969 from the vicinity of Concho Lake, Tom Green County; 18 specimens were collected in one day at College Station, Brazos County, in 1946; 35 were collected east of Lamesa, Dawson County, in 1952; 43 were collected in one month in 1950 east of Stinnet, Hutchinson County; 24 were collected in Lubbock in 1948; 40 and 20 were collected in 1948 and 1960, respectively, from Waco, McLennan County; 14 were collected by one person in one day from Fort Stockton, Pecos County, in 1942; and 26 were collected in Wichita Falls, Wichita County, in 1919.

Sighting Survey

The two surveys have some distinct biases. Whatever biases accrue to the readership of *Texas Parks and Wildlife Magazine* necessarily accrue to survey A since the overwhelming number of responses came from this group. Most responses to survey B tended to come from smaller metropolitan areas, and we believe this reflects, in part, the editorial policies of the newspapers to which the survey forms were mailed. Experience has indicated that newspapers in larger metropolitan areas were less willing to publish either of the survey forms in their original format. In addition, the decision of many newspapers in the western section of the state not to print the news release/survey could well be a reflection of the political climate in that region of the state in relation to environmental and land-use issues. Respondents appeared more likely, judging by comments on survey forms, to mail in the survey if they had seen a horned lizard than if they had not seen one.

A total of 700 responses to survey A from 119 different counties was analyzed. Of these respondents, 121 (17%) indicated that they had not seen a horned lizard within the past 10 years while living in Texas, 570 (81%) indicated they had seen a horned lizard during this time, 398 (57%) indicated they had seen one since 1990, and 586 (84%) indicated that they used to see horned lizards often. Current and historical sightings and relative declines in horned lizard abundance by region are summarized in Table 1. A complete county-by-county summary is in Donaldson et al. (1993).

Although the "percent decline" (%D) in sightings should not be taken as an absolute measure of the actual decline in horned lizard populations, it is useful as a relative measure of the abundance and

TABLE 1. Summary of sighting survey results. Individual county tallies are summarized by the regions depicted in Figure 1. (A). Survey A; #R is the number of responses originating in each region, #CS is the number of current (1990-1992) sightings of *P. cornutum*, #HS is the number of historical sightings of *P. cornutum*, and %D is a measure of the decline of *P. cornutum* in each region. (B). Survey B; #R is the number of responses originating in each region, #S is the number of actual sightings in each region, and %A is the proportion of these sightings categorized as abundant.

(A)

Region	#R	#CS	#HS	%D
East	175	64	186	66%
Central	255	114	215	45%
North	48	70	110	36%
South	101	93	128	27%
West	58	83	101	18%
TOTAL	637	424	740	

(B)

Region	#R	#S	%A
East	133	120	28%
Central	72	77	25%
North	48	50	24%
South	49	53	32%
West	35	39	20%
TOTAL	337	339	

trends of sightings between counties or regions. The magnitude of decline represented by sightings appeared to be greatest within counties which are home to large metropolitan areas. Bexar, Dallas, Harris, Tarrant and Travis counties had percent declines of 76%, 92%, 100%, 85% and 73%, respectively. In contrast, within the less populated counties of DeWitt, Atascosa, Lubbock and Midland (which each had at least 10 responses) the percent declines were 17%, 0%, 0% and 18%, respectively (Donaldson et al., 1993).

A total of 338 respondents reported sightings of *P. cornutum* in 1992 via survey B. The sightings for each county are given in Donaldson et al. (1993). The results by region are summarized in Table 1.

Except in the category of "abundance" results from surveys A and B are combined in the following summary of comments:

Abundance.—One hundred of 570 (18%) sightings of the horned lizard within the past 10 years were categorized as abundant, and 86 of 398 (22%) since 1990 were so categorized. For 1992 sightings (survey B), 90 of 339 (27%) were so categorized.

Domestic animals.—Interactions between horned lizards and domestic animals were commented upon by 15 of 1,038 (1%)

respondents. Most of these involved predation by dogs and cats. One respondent witnessed chickens preying upon horned lizards.

Fire ants.—Of the 36 respondents making comments in this category, 13 (36%) reported a decline in numbers of horned lizards following an increase in the population of fire ants, six (17%) noted the presence of horned lizards in their area and the absence of fire ants, and six (17%) observed the simultaneous occurrence of both horned lizards and fire ants. Most of these latter respondents indicated that the influx of fire ants was a recent phenomenon. One respondent from Bee County reported a decline in horned lizards prior to the influx of fire ants. Five other respondents remarked on the presence or absence of fire ants in their area without commenting on any trends in horned lizard populations.

Harvester ants.—Of the 74 responses on this subject, 52 (70%) indicated having observed horned lizards in the presence of harvester ants and 15 (20%) noted a decrease in the abundance of harvester ants prior to or simultaneously with a decline in horned lizards. Most of these attributed the decline in harvester ants to active eradication efforts involving pesticides. Seven (10%) respondents remarked that harvester ants were present in their area but that horned lizards were not, and two (3%) remarked simply upon the absence of harvester ants.

Land-use.—Comments were received from 26 respondents on this topic; no discernable trend related to horned lizard presence or abundance was apparent. Five (19%) noted a decline in horned lizards when manicured lawns appeared in their neighborhoods, whereas six (23%) noted that horned lizards were locally abundant in yards or vacant lots that were not manicured and retained native grasses. Two respondents (8%) noted a decline in horned lizards associated with the paving of roads. Four (15%) noted declines associated with cultivation of land for commercial crops such as rice, four (15%) noted horned lizards in abundance associated with farm land not currently in production, and three (12%) noted a resurgence of the species on fallow cropland. One person (4%) noted a decline in the Houston area and attributed it to the overall sinking of land, creating a wetter habitat and increasing grass cover. Another respondent (4%) noted horned lizards were abundant on 8.1 hectares of land cultivated to produce guar.

Pesticides.—Fifty respondents in this category noted pesticide/herbicide use by themselves or other local residents. Ten respondents (20%) said they or their neighbors were actively poisoning harvester ant nests, and five (10%) respondents were attempting to eradicate fire ant nests while simultaneously avoiding harvester ants. Seventeen respondents (34%) noted a decline in horned lizard abundance with increased use of pesticides, and 13 (26%) noted horned lizards doing well in areas where pesticide use was limited or had declined.

Resurgence.—Resurgence of local horned lizard populations within the past few years was attested to by 22 respondents.

Population trends.—Most of the 87 respondents commenting on long-term trends in horned lizard populations thought they had witnessed a significant decline in their area.

Field Surveys

Not all 100 localities originally targeted were completely searched because of weather, problems obtaining landowner permission to survey sites in west and north Texas, and logistical problems. At 17 original localities, property owners would not allow surveying on their property and were hostile towards a surveyor. At one locality in Presidio County, a surveyor was denied access from all property owners within eight kilometers of the site, areas surrounding it, and at an alternate locality. This survey ultimately had to be done on county property. At another site in East Texas, a surveyor was not allowed to resurvey after the initial visit because the landowner was subsequently told by friends to be cautious about letting anyone on his property looking for protected species; remaining visits were done on surrounding property within the eight kilometer radius specified in the methods. A total of 78 localities were surveyed all three times, six were surveyed twice, 13 were surveyed once, one locality was surveyed once for only two hours, two localities were visited but not surveyed, and one locality was not visited at all. All 20 localities in Central, East and South Texas and nine localities in both North and West Texas were completely surveyed.

Phrynosoma cornutum encountered during the survey.—A total of 145 individual *Phrynosoma cornutum* was encountered during the field surveys, including lizards which were captured and marked, found dead, and escaped capture (Fig. 2). These included 46 females, 41 males, and 41 hatchlings and juveniles (escapees and some dead lizards were not sexed). The majority of lizards were found between 8 June and 24 August 1992. Encounters confirm that daily lizard activity during the summer months is bimodal. Lizards were first encountered in a variety of situations: 20 on dirt and paved roads, 32 under vegetation (grasses, shrubs, trees), 17 on grass clumps or mowed grass, 14 on bare soil, three in vegetable gardens, one stuck in a vine-covered piece of chickenwire fence, and 23 on open ground running into thick vegetation. Nineteen lizards escaped capture. Of the 19 dead *P. cornutum*, 12 were found on roads or roadsides and presumably were killed by vehicular traffic. The cause of death for the seven remaining

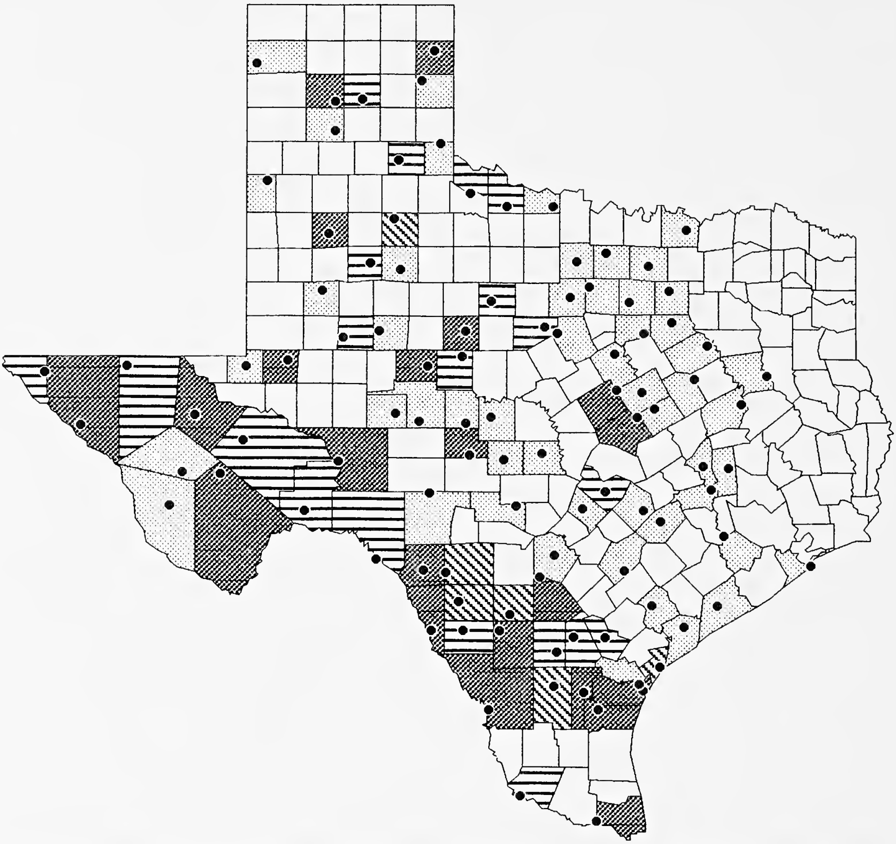

FIGURE 2. Map of Texas showing the results of the 1992 field survey for Texas horned lizards. Dots indicate the specific survey sites of Fig. 1. The counties indicated by light gray stippling contain the 52 sites where no evidence of *P. cornutum* was found. The counties indicated by dark gray stippling contain the 22 sites where only indirect evidence (sighting reports by local residents, scat, or dead lizards) of *P. cornutum* was found. Horizontal lines indicate counties containing the 20 sites where 1-4 *P. cornutum* were captured and marked.

is unknown, but is suspected to be natural predation in at least two instances.

Ninety-nine *P. cornutum* were captured and marked at 26 localities: two in Central Texas, ten in South Texas, eight in North Texas, and six in West Texas. Only two lizards were seen driving between locations, and only four were recaptured. One lizard was recaptured twice and one was recaptured on the day it was marked while the surveyor was walking to a new area on the survey site.

Most *P. cornutum* were found in South Texas where 65 were marked (Donaldson et al., 1993). Fifty-six percent (55/99) of the marked *P. cornutum* were found at five localities: 19 in Zavala County, 12 in Frio

County, ten in Aransas County, and seven each in Duval and Uvalde counties. No localities in other regions of the state had as many *P. cornutum* marked, but two were comparable. Six lizards were marked at a site in North Texas (Dickens County), and five lizards were marked, two were found dead, and one escaped at a site in Central Texas (Eastland County).

An additional 22 localities, four each in Central and North Texas, eight in South Texas, and six in West Texas, provided evidence that *P. cornutum* existed, but live lizards were not encountered (Donaldson et al., 1993). Such evidence included fecal samples (scat), dead individuals, and landowners' sightings. No live *P. cornutum* nor evidence of the species' ocurrence were found at the remaining 52 sites.

Relative abundance of Solenopsis invicta and Pogonomyrmex spp.— The size of surveyed areas varied according to habitat conditions present at each site; estimated sizes ranged from 0.83 hectares to 38 hectares. Relative abundance of *Solenopsis invicta* and *Pogonomyrmex* spp. were calculated based on the estimated area surveyed and the number of mounds counted at each site. In East Texas, the density of *S. invicta* was so high that the surveyor opted to record number of mounds encountered per meter along a transect rather than enumerate every mound: at four sites, fire ant mounds occurred every one to three meters. In central Texas, density of fire ant mounds ranged from 0/ha (five sites) to 671/ha (one site). No fire ants were reported from the nine sites completely surveyed in North Texas, and no fire ants were reported from West Texas sites. *S. invicta* mound densities in South Texas ranged from 0/ha (12 sites) to 281/ha (one site). *S. invicta* was present at only five of the 30 localities where individual *P. cornutum* were marked, found dead, or escaped capture. The densities of *S. invicta* mounds changed very little throughout the summer. Their activity was considerably reduced in mid and late summer when the ground dried and it was very hot. More time was required to check mounds for activity because the ants were deep underground.

Densities of *Pogonomyrmex* spp. were also estimated based on the number of nests encountered in each survey area. These estimates are conservative because, in many cases, surveyors would find wandering foragers but could not locate the nest entrance. This may seem unusual since harvester ants typically clear all vegetation and debris from the nest entrance to form a characteristic circle, but in several cases nests were found without any clearing at all; only a hole in the ground was observed. Alates (winged sexuals) were observed throughout the summer on several sites in Central Texas. Densities varied in all areas. In Central Texas, nest densities ranged from 0/ha (three sites) to 24/ha. In East Texas, nest densities ranged from 0/ha to one every three to six meters. In North Texas, nest densities ranged from 7/ha to 26/ha.

In South Texas, nest densities ranged from 0/ha (one site) to 38/ha (one site), and in West Texas from 0/ha (nine sites) to 25/ha. Only three of the 30 sites that had positive evidence of *P. cornutum* lacked *Pogonomyrmex* and all three were in West Texas. The maximum density of harvester ant nests on sites with horned lizards was 38/ha. *Pogonomyrmex* nest densities changed at several locations during the course of the survey. At one location in East Texas, four nests were found during the last visit that had not existed during prior visits. At two locations in Central Texas, six nests were taken over by *Solenopsis invicta*. Evidence of displacement included the dead bodies of harvester ants and the presence of *S. invicta* in the upper seed chamber of harvester ants' nests.

Resident/Property Owner interviews: pesiticide use.—Interviews were conducted at 97 localities during the survey. Many persons were uneasy when asked questions about their property, especially questions about pesticide use. Three landowners refused to answer pesticide use questions entirely. Historic pesticide use is ambiguous in many cases because residents or property owners had been on the property for only 20 to 25 years, and in some cases for even shorter periods (one to five years.)

Currently pesticide use is widespread throughout Texas. Pesticide use on or near the property was reported at 76 of 97 (78%) survey sites. Only seven sites (7%) reported no pesticide use, and at 14 sites pesticide use was unknown. Residents at 36 of the 97 localities (37%) used pesticides specifically to kill harvester ants. Pesticides and other chemicals used on insects, crops, and "weeds" included Amdro, Diazinon, diesel fuel, gasoline, Greenlight Fire Ant Killer, Orthene, Logic, Ortho Pest Granules, Spectracide, AG500, Round-up, Mirex, Malathion, Scourge in mineral oil, Resmethrin, TAT ant traps, Dursban, Sodium silicate in baby powder, Thimet, Ridomil, Sett, Pydrin, Lorsban, Pix, Arsenic dust, 2-4D, Methyl bromide, Sevin dust and liquid, Ortho Flying Insect Spray, KGRO Fire Ant Killer, Paraquat, Valpar, Benylate, Aggie Ant Killer, Treflan, Typersan, Daconil, and Prowl. Pesticide application methods varied and included hand application on single ant mounds, dusting entire yards or pastures, spraying small or large areas using tractors, and aerial applications by crop dusters.

Of the 30 sites where *P. cornutum* were marked, escaped or found dead, 22 landowners (73%) used pesticides on their property, 11 (37%) used pesticides on *Pogonomyrmex* spp. nests, and three (10%) reported no pesticide use. Current pesticide use at this subset of 30 sites was not appreciably different from the total set of study sites.

Pesticides used in the past included DDT, calcium arsenate, chlordane, and Snake Away. Information about past use is limited because many people could not remember what had been used. Individual counties have been spraying roadsides to control mosquito outbreaks for at least 25 years in some areas, such as along the Gulf Coast. One recurrent comment was that cotton crops require the use of a wide array of chemicals. Chemical use on cotton began in the 1930's with calcium arsenate, but intense use of chemicals did not begin until after World War II. It is during this time that chemicals began to be used on a large number of other crops as well (Metcalf, 1980).

Resident/Property Owner interviews: land-use.—Land-use in Texas is highly variable, and current land-use patterns do not necessarily reflect historic land-use. Many residents interviewed had not lived on their property for longer than 20 or 25 years, making it difficult to gain a historical perspective on land-use. Nevertheless, abundant historical information within the last two decades as well as current information on land-use was obtained (Donaldson et al., 1993).

Land-use at 13 of the 26 sites where *P. cornutum* was captured and marked consisted primarily of ranch land for grazing cattle. These sites had also been used historically for ranching for 30-100 years. Some ranches have limited areas of agricultural crops surrounding them. Small parcels on ranches are planted in corn, oats, or hay for livestock to eat during the winter. Of the remaining sites, three were state parks and one was a National Park. Six sites were in small communities or residential areas bordered by ranch land. One site had been a vegetable farm since 1948 with minimal pesticide use reported. One site was a county airport that rarely received aircraft, and the land-use at the remaining site is unknown because the information was not recorded during the single visit.

Land-use at the 22 sites where only evidence of *P. cornutum* was found included ranching, small communities, state parks and wildlife management areas (WMA), and a resort community. Eleven sites were ranches, two of which had been cropland until 1980, four were surrounded by cropland, and one was heavily grazed. The ranches had existed for 12 to 40+ years. Three sites were small communities, one of which was cropland approximately 30 years ago and one of which was surrounded by cropland. Three sites were state parks and one a WMA. The WMA was surrounded by cropland, and one state park was situated where increasing condominium development had taken place during the last five years. One site was a resort community that left the back section undeveloped except for a maze of dirt roads and cut and cleared swaths.

Land-use at the sites where no evidence of *P. cornutum* was found is more variable. Twelve sites were residential/urban areas. Three sites were small residences with pastures which had existed 7-25 years. Two sites were small communities situated in the middle of cropland. Ten sites were cattle ranches, with unknown use 4-25 years prior to surveys. Four sites were cattle ranches which had previously been cropland. Four sites were cattle or horse ranches with cropland. Four sites were completely cropland. Two sites were adjacent to county airports, one of which was also used to produce hay twice a year. Six sites were state parks and recreational areas. The recreational areas were generally described as high-use.

Discussion

Populations

Phrynosoma cornutum populations appear to be robust in South Texas, where individuals were captured and marked at 10 localities, and evidence of the presence of *P. cornutum* was found at an additional eight localities. The Texas horned lizard also appears to be doing well in North and West Texas; but, the inability to completely survey some sites in both areas render the results ambiguous. West Texas, in particular, should have produced better results, since the species is historically common and none of the putative factors influencing populations of this species are known to be operating there. The field survey appears to confirm public perception and historical data that *P. cornutum* has declined in East and Central Texas. The greatest decline of *P. cornutum* has occurred in East Texas where no individuals were found. Central Texas also shows an apparent loss of populations; only six sites show positive evidence that lizards were still there, and lizards were actually captured at only two of these sites. At the remaining four sites, lizards had been seen only rarely by property owners or only scat were found.

Pesticides

Pesticide use does not seem to be a strong factor influencing the presence or absence of *P. cornutum* since the pattern of pesticide use on sites with positive evidence of the lizard was similar to that for all sites surveyed. Pesticide use information is qualitative, however, and the assumption that pesticides play no part in declining *P. cornutum* populations should be viewed with caution. Results show that 37% of property owners are currently using pesticides to kill *Pogonomyrmex*; since the Texas horned lizard specializes on these ants for food, eliminating them will have a negative effect on populations in the future. We do not know how *P. cornutum* may be affected if individual lizards eat poisoned ants. Hibernating or aestivating lizards and incubating eggs may also be susceptible to applied chemicals that leach through the soil. Pesticide use did not become widespread in Texas until the late 1940's-early 1950's, and pesticides are used in larger quantities on cropland than land with other uses.

Land-use

In the scope of this study, land-use is the primary indicator for the presence or absence of *P. cornutum.* Agriculture seems to be the primary factor associated with the absence of *P. cornutum* populations on the study sites, with urbanization running a close second. Agricultural activities can directly lead to declining populations through several different avenues. Since horned lizards hibernate or aestivate at soil depths routinely disturbed by plowing or tilling, such activity may kill them directly or indirectly by exposing lizards to harsh climatic conditions they seek to avoid. If plowing occurs in the summer, incubating *P. cornutum* eggs could be destroyed. Plowing land also destroys the habitat of *P. cornutum,* forcing lizards into surrounding, often suboptimal habitats as witnessed by several property owners questioned during this survey. Crops tend to promote the use of chemicals in the area. Several persons interviewed said that *P. cornutum* was abundant around and in cotton fields in the 1930's and 1940's, when pesticide use was low and cotton was hand-picked instead of being harvested by using defoliants and machines.

Fire ants

The impact of *Solenopsis invicta* on *P. cornutum* is unclear. Scale effects may be important as demonstrated for small mammals (Killion and Grant, 1993). Many areas where this ant species occurs in high densities are also areas subject to landscape disturbances (Porter and Savignano, 1990). Five instances of *P. cornutum* swarmed by ants were recorded, but the lizards were already dead, and their deaths cannot be directly linked to fire ants. *S. invicta* may impact *P. cornutum* in a variety of ways, however. It is unknown whether horned lizards can forage, grow and reproduce normally on a diet consisting of *S. invicta* when other ant species become rare. Evidence that fire ants kill other arthropods including *Pogonomyrmex* spp. was recorded during this status survey, and their negative impacts on the diversity and abundance of native arthropods have been well documented (Porter and Savignano, 1990; Morris and Steigman, 1993). Such impacts may decrease the availability of adequate food resources to the Texas horned lizard. Another feature of *S. invicta* which may affect *P. cornutum* is the subterranean foraging tunnel system these ants construct below their mounds (Markin et al., 1975). In areas of high *S. invicta* densities, it may be impossible for horned lizard eggs to incubate or individuals to hibernate successfully.

Projected Outlook For *Phrynosoma Cornutum* In Texas

Populations of *Phrynosoma cornutum* in South and far West Texas will probably remain stable unless landscape-scale changes occur in land use. *Solenopsis invicta* is not expected to invade most of South Texas because of the hot, dry climate, but it probably will invade urban and residential areas as it has in West Texas (Drees and Vinson, 1991). We suspect the remaining disjunct populations in East and Central Texas will continue to decline with continued agricultural activities and urbanization, with the ongoing invasion of *Solenopsis invicta* a contributing factor. Populations in North Texas may also decline in areas where these factors operate.

Conservation measures to restore *Phrynosoma cornutum* to areas where the species has declined or disappeared should address the re-establishment of native vegetation communities, and the maintenance of vegetation corridors which remain unplowed and untreated with broadcast chemicals. Domestic animals such as dogs and cats should be controlled to reduce predation pressure. Conservation measures should seek to prevent the invasion of *Solenopsis invicta,* or to control this species while minimizing impacts to native arthropod communities. It should perhaps go without saying that commercial trade in this species should be curtailed and existing regulations to that effect enforced.

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EFFECTS OF THE INCUBATION ENVIRONMENT ON THE SIZE AND INCUBATION TIME OF *SCELOPORUS UNDULATUS CONSOBRINUS* HATCHLINGS

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Abstract.—The effects of two different egg incubation environments on neonate size of *Sceloporus undulatus consobrinus* were studied. Egg size was not significantly different among the two treatments, but hatchlings from the 32 °C treatment (mean water potential = -400kPa), were significantly longer (Snout-Vent Length; SVL) and heavier than hatchlings from the 24 °C treatment (mean water potential = -300kPa). The incubation environment influenced hatchling size significantly in both years of the study. Implications of these findings are discussed regarding the observation of larger hatchling *Sceloporus undulatus* in the field late in the season. *Key words*: Iguanidae; *Sceloporus undulatus*; eggs; hatchlings; incubation environment.

Life history variation in iguanid lizards has been extensively studied (Tinkle, 1969; Tinkle and Ballinger, 1972; Tinkle and Dunham, 1986; Jones and Ballinger, 1987; Dunham et al., 1988). Several iguanid lizard species change their egg and clutch size in successive broods (Ferguson and Bohlen, 1978; Nussbaum, 1981; Ferguson and Snell, 1986), some reducing the size of the latter clutch (Tinkle and Ballinger, 1972; Derickson, 1976; Ferguson and Snell, 1986). In *Sceloporus undulatus garmani*, increased egg size accompanied by reduced clutch size is advantageous because larger hatchlings (presumably from larger eggs) are better adapted to late season conditions and enjoy higher survivorship than small hatchlings (Ferguson et al., 1982; Ferguson and Fox, 1984). Change in hatchling size has been shown to be under endogenous control in *Sceloporus undulatus* (Ferguson and Snell, 1986). Most of the above investigations have de-emphasized possible proximate causes of hatchling size variation.

Derickson (1976) found that second or third clutch *Sceloporus graciosus* and *S. undulatus* eggs contain higher energy than first clutch eggs. He concluded that the higher energy content of late season eggs is the proximate cause of larger hatchlings. However, the incubation environment also influences egg mass, hatchling size, incubation time, and sexual differentiation in several turtles and squamates (Bull and Vogt, 1979; Muth, 1980; Packard et al., 1980, 1981, 1987; Gutzke et al., 1987; Ratterman and Ackerman, 1989; Phillips et al., 1990; Van Damme et al., 1992). Sexton and Marion (1974) reported that temperature affected incubation time in a Missouri population of *Sceloporus undulatus*. But, Marion et al. (1979) found no size differences in *S. undulatus* hatchling weights between first and second clutches incubated at the same temperature. Tracy (1980) reported no effect of environmental water potential on hatchling size in *S. undulatus*. However, both of these studies (Marion et al., 1979; Tracy, 1980) did not control for the effects of egg size in their experiments.

Because of the confusion regarding proximate influences on hatchling size in *S. undulatus,* we examined how egg incubation environments affect hatchling size of *Sceloporus undulatus consobrinus*. Our purpose was to determine if the egg incubation environment is a possible proximate cause for larger late season hatchlings. We did not try to tease apart the different effects of temperature and water potential. These factors are correlated, and they vary in natural nests as well as in boxes of vermiculite.

Materials and Methods

Twenty-two female *S. u. consobrinus*, collected in Callahan County, Texas, on 3 May 1987 and 7 April 1988, were maintained in plastic boxes (39.5 x 27 x 16 cm) in our laboratory. Each box contained a moistened substrate of sand 30-35 mm deep. Illumination and heat was provided by 75 W General Electric flood lamps, and 40 W General Electric ultraviolet (BL) lights. Photoperiod was set at 14:10 (Light:Dark) and was automatically controlled at this cycle until oviposition. Females were fed crickets until satiated three days per week.

Fifteen of the twenty-two females were gravid when collected and laid a total of 121 fertile eggs. All females laid eggs within one week of captivity. To control for maternal influence on egg and hatchling size, eggs from each clutch were assigned to one of two treatment groups. Each clutch was divided in half so that half the eggs were assigned to one treatment group, and the other half to the second treatment group. For clutches with odd numbers of eggs, the extra egg was randomly assigned to one group or the other. We attempted to balance the total egg number in each treatment group overall. There was no significant difference in egg size between treatments.

The first group was incubated at high temperature (32±0.5°C), and the second group at low temperature (24±0.5°C) each in a Sherer constant temperature chamber. The first group was exposed to a mean water potential of approximately -400 kPa, SE±50 kPa, n=9; the second group, to a mean water potential of about -300 kPa, SE±50 kPa, n=6. Because the eggs take up water due to gradients in water potential and vapor pressure (Packard and Packard, 1988), the water potential measures were not identical. However, we have shown that in *Uta stansburiana* eggs, water potential differences of this magnitude have no significant impact on hatchling length or hatchling mass (Ferguson et al., 1990). Water potentials of vermiculite samples were measured using a Wescor HR-33T microvolt meter and c-52 sample chamber. There were 60 eggs in the first treatment group and 61 in the second treatment group. Eggs were retrieved within 12 h of oviposition, weighed to the nearest mg, and placed in two boxes (31.5 x 16.5 x 8.5 cm), filled with 300 g of #3 vermiculite and 210 g distilled water. Eggs were buried approximately 2 mm below the surface of the vermiculite to prevent condensation on the egg surface. These boxes were covered with a 0.5 mil plastic wrap secured by rubber bands and incubated in Sherer constant temperature chambers. Eggs were transferred to newly mixed boxes of vermiculite every two weeks, at which time additional water potential measurements were taken. We determined incubation time (days), egg mass (g),

TABLE 1. Characteristics of eggs and hatchlings of *Sceloporus undulatus consobrinus* incubated at 24°C and 32°C. Differences in hatchling mass, hatchling SVL, and incubation time were all significant based on ANOVA. Initial egg mass was not significantly different between treatments.

Variable	Treatment Temperature	Mean	SE	SD	n
Initial Egg	24	266.42	4.22	30.74	53
Mass (mg)	32	266.48	3.42	24.19	50
Hatchling	24	329.7	5.13	37.34	53
Mass (mg)	32	345.2	4.97	35.18	50
Hatchling	24	21.5	0.13	0.97	53
SVL (mm)	32	22.5	0.09	0.64	50
Incubation	24	96.75	0.42	3.09	53
Time (days)	32	33.74	0.43	3.01	50
Hatchling	24	24 males: 29 females			53
sex ratio	32	25 males: 25 females			50

hatchling mass (g), hatchling snout-vent length (mm), and hatchling sex (by examination of the gonads).

The potential covariate, egg mass, was not significantly different between treatments. We therefore analyzed the data from the two years by mixed model, nested analyses of variance (year nested within treatment); with treatment as a fixed effect and year as a random effect (SAS Institute Inc., 1991). The dependent variables were: the number of days of incubation, hatchling SVL, and hatchling mass.

RESULTS

The eggs in group 1 (32°C) hatched significantly earlier than those in group 2 (24°C) regardless of year (Tables 1 and 2). Variation between egg boxes was not significant. In group 1, eggs hatched in a mean of 33.7 days, with 83.3% (50 of 60) success. Eggs in group 2 hatched in a mean of 96.8 days, with a 86.9% (53 of 61) success. There was both a significant difference in hatchling SVL and hatchling mass between treatments, with group 1 hatchlings being significiantly longer and heavier than group 2 hatchlings in both years (Tables 1 and 2). Incubation environment significantly influenced the size of hatchlings (length and mass) which came from similarly sized eggs in both years of the experiment. There was no effect on hatchling sex due to incubation environment (Table 1).

DISCUSSION

That eggs incubated at 24°C took an average of 96.8 days to hatch is interesting because eggs of the same species incubated at 25°C take nearly 30 days less to hatch (Sexton and Marion, 1974). Sexton and

TABLE 2. Nested ANOVA of incubation time, hatchling mass, and hatchling snout-vent length for *Sceloporus undulatus consobrinus* eggs incubated and hatched at two different temperatures.

Source	DF	Type I SS	F	P
A. Incubation Time				
Temperature	1	102162.76	11117.66	<0.0001
Year (Temp)	2	47.69	2.60	0.0797
B. Hatchling Mass				
Temperature	1	6246.67	4.73	0.0321
Year (Temp)	2	4878.33	1.85	0.1634
C. Hatchling Snout-Vent Length				
Temperature	1	22.77	35.40	<0.0001
Year (Temp)	2	47.69	2.60	0.0797

Marion (1974) incubated *Sceloporus undulatus* eggs from Missouri at 20°C and 25°C. They reported a 67% hatching success in their 25°C treatment (mean incubation time = 68.9 days for first clutch eggs), but no hatching success at 20°C. Twenty-four degrees may be the minimum tolerated for *S. u. consobrinus*. Muth (1980) found similar results in incubation of *Dipsosaurus dorsalis* eggs. In contrast to Tracy's (1980) results we found that incubation environment can have a significant effect on hatchling size in this species. Our results also contrast with those of Phillips et al. (1990); these investigators found in *Iguana iguana* that high temperatures accelerated development but resulted in smaller hatchlings, with larger hatchlings being produced at lower temperatures with high water potentials. However, the range of incubation temperatures was slight (2°C), and were not near the limits of temperature tolerance for successful development as in our experiment. Also, Van Damme et al. (1992) found that neonates of the lizard *Podarcis muralis* were larger, heavier, hatched sooner, and had better performance (sprint speeds) when incubated at lower rather than higher temperatures. These contrasting results may reflect differences in incubation environment tolerance between these species.

We extend the contentions of Derickson (1976), Ferguson and Bohlen (1978), and Ferguson et al. (1982). These authors implied that larger late-seasonal hatchling *Sceloporus* observed in the field result exclusively from larger second clutch eggs produced by females. Thus, selection favoring larger hatchlings should also favor larger eggs, because larger hatchlings (presumably from larger eggs) enjoy higher survivorship than small hatchlings (Ferguson et al., 1982; Ferguson and Fox, 1984). Our study shows that in this population of *S. u. consobrinus* a significant difference in field incubation conditions for second than for first clutch eggs now seems to be a feasible cause for larger late-seasonal hatchlings. If field incubation conditions for *S. undulatus* typically have major influence on hatchling size as in *Conolophus* (Snell and Tracy, 1985), then genetic covariance between egg and hatchling size may be weaker than currently assumed. The indirect effect of selection for large hatchling size on the evolution of large egg size may be weaker or less predictable than currently proposed.

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BEHAVIOR OF THE ZEBRA-TAILED LIZARD DURING A TOTAL SOLAR ECLIPSE

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Abstract.—The behavior of ten *Callisaurus draconoides* in a 20 m^2 enclosure of natural microhabitat in Baja California Sur, México, were monitored five days prior to and during a total solar eclipse on 11 July 1991. During the eclipse, lizard behavior was similar to that following sunset, but the short time-span of the eclipse did not allow all the lizards to assume sleeping shelters. *Key words:* behavior; *Callisaurus draconoides;* eclipse; lizard; México.

The changed behavior of birds (Elliot and Elliot, 1974), chimpanzees (Branch and Gust, 1986), rodents (Advani, 1981) and fishes (Pandey and Shukla, 1982) has been observed during solar eclipses, but similar data are not available for lizards. The zebra-tailed lizard, *Callisaurus draconoides,* is a medium-sized (55-75 millimeters snout-vent length) inhabitant of North American deserts (Asplund, 1967; Vitt and Ohmart, 1977; Stebbins, 1985). The purpose of this study is to report the behavioral changes of *C. draconoides* during a total solar eclipse.

Materials and Methods

The study was conducted at "El Comitán", 17 kilometers west of La Paz, Baja California Sur, México (24°08′ N; 110°12′ W). The area is a coastal lowland with loam-sandy soils covered with a xerophitic-scrub (León De la Luz and Troyo, 1985), composed mainly of the cacti *Pachycereus pringlei, Macharocereus gummosus* and the shrubs *Jatropha cinerea* and *Fouqueria diguetti.* The average annual temperature is 23.6°C, and the mean annual precipitation is 181 millimeters concentrated mostly in August and September (Hastings and Humprey, 1969; García, 1983).

Ten adult *Callisaurus draconoides* from this desert scrub habitat were placed in a 20 m^2 enclosure (of similar habitat) surrounded by a metal wall 40 centimeters high. We monitored the behavior of the lizards twice daily, from 1034 to 1314 hr (the time interval of the eclipse on 11 July 1991) and at sunset (1909 hr) for five days prior to the eclipse.

On 11 July 1991 we recorded environmental characteristics at 10-minute intervals (Table 1) and continuously recorded the behavior of the individuals from 0909 to 1404 hr (Table 2). Air and soil temperatures, in both shade and sun were recorded with a remote sensor electronic thermometer (CIB-3), the incident and reflected solar radiation with a pyranometer, the humidity of the air with an electronic hygrometer (CIB-18), and the wind direction and speed with an anemometer.

Results

Between 1000 and 1200 hrs during the five days before the eclipse, lizards avoided the open soil and spent most of their time in the shade of shrubs and rocks. The mean soil and air temperatures in the shade

TABLE 1. Environmental characteristics recorded at the study site during the total solar eclipse of July 11, 1991.

Hour	Temperature (°C)				Humidity	Incident	Reflected	Wind	Wind
	Air		Soil			rad.	rad.	speed	dir.
	shade	sun	shade	sun	%	(w/m^2)	(w/m^2)		
0909	32.3	34.7	36.5	43.3	33.7	499.9	99.1	1.0	SW
0919	32.9	35.5	37.0	43.8	33.3	525.3	101.9	2.8	SW
0929	33.3	36.0	37.5	44.8	32.9	550.2	105.8	1.7	SW
0939	33.9	37.0	38.2	45.5	32.5	574.1	110.2	2.0	SW
0949	34.5	37.7	38.4	46.1	32.1	596.3	114.5	1.5	SW
0959	35.0	37.9	39.6	46.9	31.7	617.7	115.1	0.7	SW
1009	35.8	38.9	39.9	47.9	31.3	638.2	119.1	2.1	W
1019	35.8	39.1	41.0	48.6	31.3	659.0	122.8	0.6	SW
1029	36.4	39.1	41.4	49.4	31.3	677.4	123.5	1.1	SW
1039	36.8	39.9	41.3	49.2	31.3	672.2	122.4	1.5	SW
1049	36.8	39.7	41.9	49.0	32.1	630.3	112.5	1.3	SW
1059	37.0	40.1	42.3	48.5	32.1	563.9	99.3	1.2	W
1109	37.0	40.1	42.5	48.0	32.5	475.2	82.3	0.8	SW
1119	37.0	40.1	42.7	47.1	32.9	370.7	62.3	0.8	SW
1129	36.6	39.9	42.1	46.9	33.3	255.0	41.1	1.1	NW
1139	36.2	39.5	42.0	46.7	33.3	137.7	20.1	1.1	SW
1149	35.4	38.8	42.0	46.3	34.1	30.3	1.2	1.1	W
1159	34.9	37.3	41.7	46.2	34.1	0.0	0.0	1.4	W
1209	34.3	36.8	41.0	45.5	34.1	57.2	5.9	1.5	W
1219	34.1	36.8	41.3	47.0	32.9	183.3	28.7	2.0	W
1229	34.1	37.0	41.2	47.6	31.7	304.1	50.5	1.6	W
1239	34.3	37.2	41.2	48.3	32.5	431.1	73.2	1.3	W
1249	34.7	37.8	41.0	48.6	32.5	548.4	94.5	1.7	W
1259	35.2	38.3	41.0	48.9	32.9	649.8	112.8	1.3	W
1309	35.8	39.0	41.3	48.8	33.3	730.7	127.9	0.8	W
1319	36.6	39.6	41.6	49.2	33.3	782.8	137.4	0.8	SW
1329	37.2	40.2	41.7	49.3	34.9	790.6	136.9	1.2	SW
1339	37.2	40.4	41.7	49.4	33.3	785.2	136.7	0.6	SW
1349	37.4	40.5	41.9	49.2	36.4	774.3	133.0	1.1	SW
1359	36.6	40.1	41.8	49.0	38.4	765.1	132.3	1.4	SE
1404	36.4	40.0	41.9	49.1	39.2	758.7	132.3	1.7	SW

were 41.4°C, and 36.8°C, respectively. In direct sun, the mean temperature of the soil was 49.8°C, and the mean air temperature was 39.6°C.

After sunset, prior to the eclipse, the lizards retreated into sleeping shelters. They buried themselves at depths 1.2 to 2.5 centimeters below the loam-sandy soil surface (littered with leaves and debris) and near or underneath shrubs. At sunset the mean temperature of the soil in the shade was 38.7°C, and the mean air temperature was 31.2°C.

Changes in environmental factors were recorded during the eclipse (Table 1). Sudden decreases occurred in incident and reflected solar

TABLE 2. Behavior of the lizards during the total solar eclipse of July 11, 1991.

Hour	Behavior recorded
10:00	Excepting lizard 7, which was on the sand directly under the sun and lizard 4 which had its forelegs on a small rock vertically positioned, all other individuals were located under the shade of shrubs and small rocks.
10:05	Lizard 3 moved 52 cm from below a shrub in the shade to a shaded place near a rock (pattern #1). Movements were fast out of the shade, but when it reached the shade the movements became sluggish. All the other individuals are practically without movement, sluggish in the shade.
10:08	Lizard 5 moves quickly 10 cm out of the shade and catches a small cricket and proceeds to eat it under the sun and moving the head vigorously from one side to the other.
10:09	Lizard 9 moved (pattern #1) 65 cm from one shaded point to another.
10:12	Lizard 7 moved 34 cm to the shade of a shrub. When it reached the shade it became sluggish.
10:14	Lizard 5 returned 15 cm to the shade.
10:34	Lizard 8 moved 40 cm from one shaded place to another (pattern #1).
10:58	Lizard 6 moved fast 30 cm to an open space and proceeded to eat a small hemipteran but the lizard did not perform vigorous movements of the head from side to side. Lizard 6 stayed in the sun.
11:16	Lizard 4 became flattened in the same position on a rock.
11:18	Lizard 2 closed its eyes.
11:20	Lizard 4 closed its eyes.
11:23	Lizard 8 buried itself under the soil exactly where it was. It buried itself under the soil by moving quickly all legs and moving the body from one side to other (pattern #2).
11:27	Following pattern #2 lizard 9 proceeds also to bury itself where it was lying. In both cases the lizards were finally located about 2 cm below the soil surface.
11:34	Two of the 10 lizards were buried below the soil; one was flattened to a rock and the other 7 were motionless with their bodies flat to the soil, with the eyes closed and underneath shrubs.
11:40	There was no movement.
12:17	All lizards same as at 11:34.
12:20	Lizard 2 moved 3 cm.
12:26	Lizard 5 executed pushups in the place where it was located.
12:28	Lizard 9 emerged to the surface.
12:36	Lizard 8 emerged to the surface.

TABLE 2. Continued

12:40	Three lizards were active and the other 7 had their eyes open but were still motionless.
12:42	Excepting lizard 4 all the lizards move to the shade of shrubs and rocks.
12:54	All lizards are in shade, awake but inactive.

irradiation with the onset of the eclipse, but air and soil temperatures decreased slowly. Wind speed and humidity increased slightly and wind direction exhibited little change during total eclipse (6 min, 27 sec).

Table 2 shows the behavior of lizards during the eclipse period. These data are summarized in Fig. 1.

DISCUSSION

During the solar eclipse *C. draconoides* exhibited various postures associated with behavioral thermoregulation (Heath, 1965; DeWitt, 1971; Muth, 1977) and two lizards performed activities similar to those observed during sunset, i.e., they buried themselves below the soil surface (Grenot et al., In Press). However, the other eight lizards only

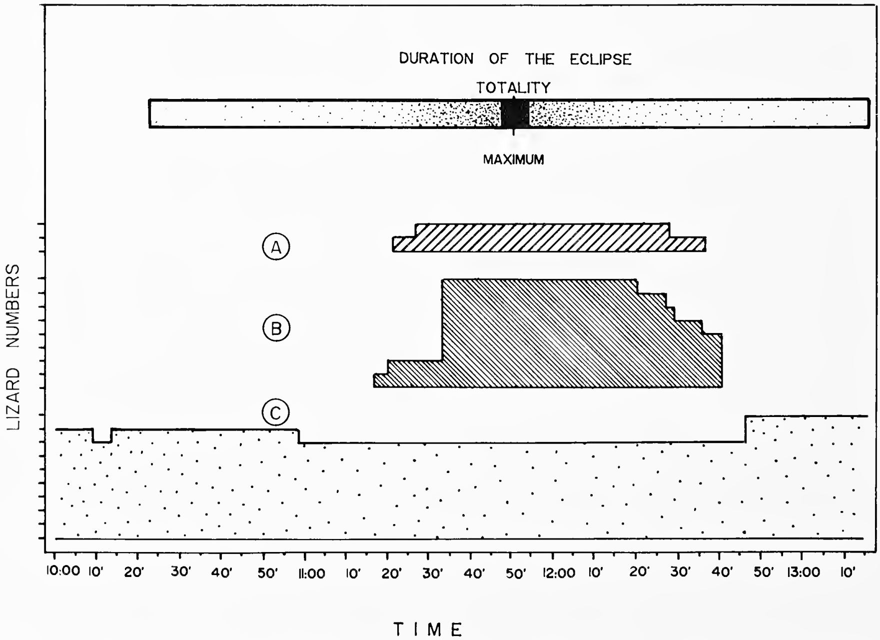

FIGURE 1. Summary of lizards' behavior during the eclipse. A) Numbers of lizards buried, B) Numbers of lizards with eyes closed, C) Numbers of lizards in shade of shrubs.

became motionless, with eyes closed and bodies flat against the substrate.

The two buried lizards emerged from their subterranean retreats and became active following the eclipse, resuming behavior similar to that during the early hours of morning. However, because of the sudden increase of temperature and radiation from the nearly directly overhead sun, the lizards almost immediately took refuge in shaded places.

We conclude that, like other animal species (Delye, 1973; Lescure, 1975), individuals of *C. draconoides* became confused by a total solar eclipse and proceeded to perform the same behaviors as normally exhibited at the end of the day, during sunset. However, probably because of the short time-period of the total solar eclipse (6 min, 27 sec), most of the individuals (80%) failed to burrow into a subterranean sleeping shelter before the sunlight reappeared.

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A SURVEY OF CONTAINER-BREEDING MOSQUITOES IN MCLENNAN COUNTY, TEXAS

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Abstract.—Mosquito populations were sampled monthly from cemetery flower vases from June through December, 1992. Eight different species were collected. Four (*Aedes albopictus, Ae. triseriatus, Ae. hendersoni,* and *Ae. epactius*) were collected consistently throughout the summer. One species (*Culiseta inornata*) was collected in early summer and late fall. Three species (*Culex restuans, Toxorhynchites rutilus septentrionalis,* and *Orthopodomyia signifera*) were collected occasionally and only as isolated individuals. Of the eight species collected, three (*Aedes albopictus, Ae. hendersoni,* and *Orthopodomyia signifera*) were previously unreported in McLennan County. The absence of *Ae. aegypti* in the samples was important. *Key words*: container-breeding mosquitoes; Texas; McLennan County.

No current list of mosquitoes exists for McLennan County, Texas, and the only recent information relating to mosquito populations in central Texas is provided by Fournier et al. (1989) who identify 25 species in six genera as present in McLennan County. That information is derived from various collection records dating back to 1977. Consequently, I determined that a survey of selected breeding sites was in order as considerable change may have occurred since the last survey. This was especially important because *Aedes albopictus*, the Asian Tiger mosquito, became established in Texas in 1985 (Sprenger and Wuithiranyagool, 1986) and has since spread throughout the United States (Hawley, 1988). *Ae. albopictus* is of concern as it is a vector of various viral diseases in Asia. It is not listed as being in McLennan County in Fournier et al. (1989). But, I know from personal observation that it is well established.

Resources were not available to undertake a comprehensive survey of mosquito populations. Consequently, this canvas was restricted to container-breeding mosquitoes (those that lay their eggs in artificial vessels which fill with water). Container-breeding mosquitoes can usually be collected in almost anything that holds a small pool of water. Typically, old tires, cans, cups, and other similar small containers with water can support larval development. Since such containers tend to be ephemeral and I was interested in conducting a survey over several months, I decided to sample populations from more permanent containers. Flower containers in cemeteries have been shown to provide excellent sites for larval collections (Schultz, 1989; O'Meara et al., 1992a; O'Meara et al., 1992b). Female mosquitoes readily lay their eggs on the inner surfaces of such containers, above any standing water. When flooded with rain water (or water from a

Table 1. Numbers of mosquitoes in monthly samples of cemetery vases.

Month	Positive Sites	*Aedes albopictus*	*Aedes triseriatus*	*Aedes hendersoni*	*Aedes epactius*	*Culex restuans*	*Culiseta inornata*	*Toxorhynchites rutilus s.*	*Orthopodomyia signifera*
June	60	1913	99	34	57	4	237	5	1
July	30	1341	39	23	17	0	30	5	0
August	19	459	43	9	15	0	0	0	4
September	16	116	11	20	13	0	0	1	0
October	3	45	0	0	0	0	0	0	0
November	1	13	0	0	5	0	0	0	0
December	4	5	0	0	0	0	23	0	0
Total	133	3892	192	86	107	4	290	11	5

sprinking system), the eggs hatch and the larvae develop. Because these flower vessels are more permanent than discarded cups, cans, and tires, more organic debris tends to settle to the bottom, and the container may eventually assume some characteristics of tree holes. Thus, a wider range of species can be collected from them as compared to other artificial containers.

MATERIALS AND METHODS

Several local cemeteries were assessed for their potential as collection sites. Larvae require containers with standing water for development. Containers made of stone have been shown to be better breeding sites than metallic containers or stone containers with metallic liners (O'Meara et al., 1992b). Female mosquitoes need places to rest prior to oviposition. So, desirable characteristics include shrubs and trees associated with graves having appropriate (non-metallic) containers for flowers. Of the cemeteries in Waco, two were suitable. Because they were adjacent to each other, I settled on the older and larger of the two. That cemetery covers over 0.6 sq km. It is in an old and established part of the city with large trees, many shrubs and bushes. Because it would take too long to survey such a large cemetery, an approximately 0.16 sq km portion was used as the sampling site.

From January through May, 1992, central Texas experienced greater than normal amounts of rain. As standing rainwater levels increased, I decided that was the best time to begin a survey. Sampling began in early June and was performed at a similar time each month through December. Sampling the site took three days each month. Sampling consisted of walking the site and inspecting any vessels associated with the graves. Those vessels which held water were examined for the presence of mosquito larvae. Larvae were removed using a 15 milliliter kitchen baster. The water and larvae from each sample were put in a 500 milliliter jar and brought back to the lab. In the lab, each sample was put into a 22 x 12 x 6 centimeter Nalgene™ pan covered with a sheet of Plexiglas®. If necessary, food in the form of a liver powder suspension (15 grams liver powder in 1 liter tap water) was added to the water. All pans were kept under constant environmental conditions (26° C, 80% R.H., 16:8 light: dark cycle). Upon pupation, the pupae were removed to temporary emergence cups. As adults emerged, they were classified using various keys (Darsie and Ward, 1981; Fournier et al., 1989).

RESULTS

The results of the survey are presented in Table 1. Over the seven month period, a total of 4,587 mosquitoes were identified from 133 different samples. These included eight species of mosquitoes in five genera. Over 84% of the mosquitoes found were *Ae. albopictus.* This is of note because it is previously unreported in McLennan County. *Ae. triseriatus* and *Ae. epactius* were found in much smaller proportions (4.2% and 2.3%, respectively). They are both previously reported in McLennan County. *Ae. hendersoni* is closely related to *Ae. triseriatus* and also previously unreported in McLennan County. It was found in low numbers (1.9%).

Species of four other genera were also found during the survey. *Culex restuans* was found in low numbers (0.1%) and only in June.

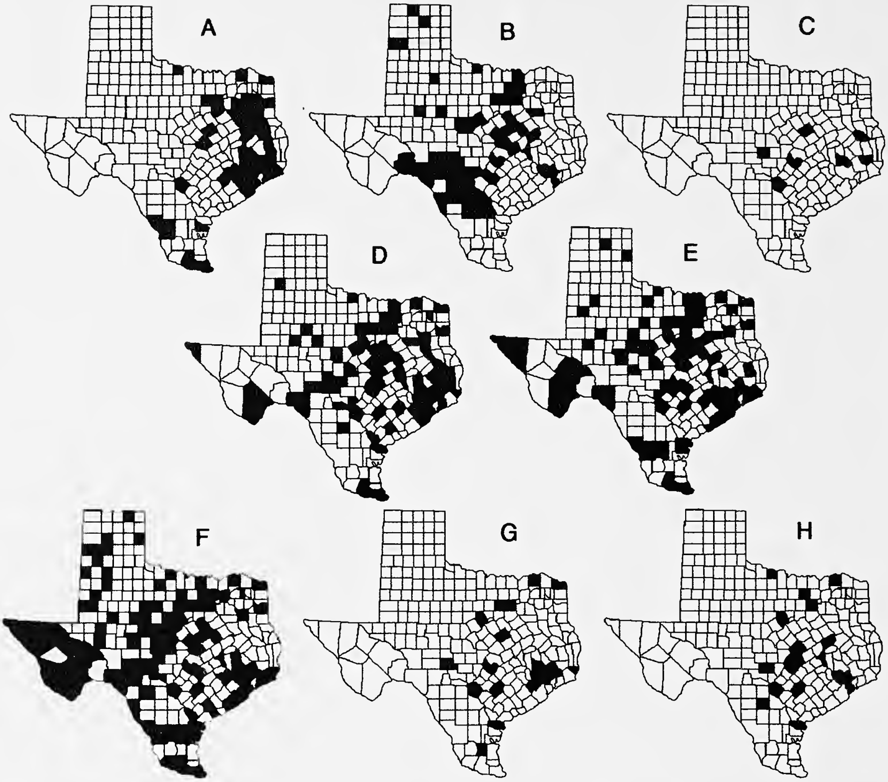

Figure 1. The distribution of (A) *Aedes albopictus,* (B) *Aedes epactius,* (C) *Aedes hendersoni,* (D) *Aedes triseriatus,* (E) *Culex restuans,* (F) *Culiseta inornata,* (G) *Orthopodomyia signifera,* and (H) *Toxorhynchites rutilus septentrionalis* (Compiled from Fournier et al., 1989).

Toxorhynchites rutilus septentrionalis was found regularly in small numbers (0.2%). *Culiseta inornata* was the second most common mosquito found (6%). All three of these were previously reported in McLennan County. *Orthopodomyia signifera* was found only occasionally during the summer, and only in small numbers (0.1%). Mosquitoes of this genus have never been reported in McLennan County.

Monthly trends over the period of the survey followed expected patterns. Population sizes were largest earlier in the summer when the amount of standing water was greatest. As the summer progressed, and rains were no longer sufficient to maintain standing water in the flower vessels, the numbers of mosquitoes decreased. However, populations were maintained even late in the summer as a result of the regular program of watering at the cemetery. Beginning in fall, population levels declined with the onset of cooler temperatures.

Discussion

This survey presents three important points. First, mosquitoes of eight different species were collected. The reported distributions of the eight species are shown in Fig. 1. Three of the species (*Aedes albopictus, Ae. hendersoni,* and *Orthopodomyia signifera*) had never been reported in McLennan County.

This is the first record of *Ae. albopictus* in McLennan County. This is understandable because this species was first found in Texas in 1985, and this is the first formal survey in McLennan County since that time. Fournier et al. (1989) report the presence of *Ae. albopictus* in neighboring Bell County. So, its presence in McLennan County is predictable. It is not surprising to find *Ae. albopictus,* as it is fast becoming the most common container-breeding mosquito in Texas.

One of the mosquitoes collected (*Orthopodomyia signifera*) represented a genus that had never been reported in McLennan County. This collection is more surprising because this mosquito has not been found in any adjacent counties. The closest counties for which there are records of this mosquito are Dallas, Tarrant, Erath, and Travis. It is impossible to tell whether this represents a discontinuity in its distribution, or is just indicative of an incomplete system of surveys in northern and central Texas. This mosquito typically develops in water associated with the roots of trees and is only occasionally found in the types of containers sampled in this survey (Carpenter and LaCasse, 1955). Consequently, its low levels in this survey may not be a true indication of the level at which local populations exist. If it is found in low levels in an unusual habitat, it may be present at persistent levels in its normal habitat.

A second important point is an interesting negative finding. No *Ae. aegypti* were found in this survey. *Ae. aegypti* used to be the most common container-breeding mosquito in central Texas. The displacement of *Ae. aegypti* by *Ae. albopictus* has been observed elsewhere (Hawley, 1988).

A third important point is the presence of *Toxorhynchites rutilus septentrionalis.* Although this mosquito has been reported in McLennan County before, finding it was somewhat surprising. It was consistently found at low levels during the survey. The low levels are easily explained by its predatory nature—preying upon larvae of other mosquitoes. As such, a vessel of water can support a limited number of larvae of this species. However, the presence of the mosquito brings up some interesting questions as to its ability to survive periods of dryness and winter. The other mosquitoes found in this survey can survive such periods by diapausing as eggs. Little is known about this in *Toxorhynchites rutilus septentrionalis,* but it seems doubtful that diapause as eggs would be possible. Carpenter and LaCasse (1955) report that this species overwinters either as adults or as mature larvae. Almost all of the sites involved in this survey were dry during the months of November and December. This leaves two possibilities. Either they overwinter as adults, or, if they do overwinter as mature larvae, they are doing so in the muddy debris at the bottom of these containers.

Finally, it is worth noting that this survey was conducted following one of the wettest springs in recent years. As such, I considered it reasonable that mosquito numbers (and diversity) would be quite high. So, some of the species found in this study may not be permanent inhabitants of this area. The extraordinary conditions might have allowed them to exist during that time while they may not be present in summers with typical rainfall. I am confident that the various species of *Aedes* are all permanent residents. However, my collection of *Orthopodomyia signifera* could be an isolated event.

Representative samples have been preserved and are kept in the Medical Entomology Laboratory at Baylor University, Waco, Texas.

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NUTRIENT CONTENT OF IMPORTANT DEER FORAGE PLANTS IN THE TEXAS COASTAL BEND

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Abstract.—Nutritional analyses for two years of crude protein (CP) and *in vitro* digestible organic matter (IVDOM) were conducted on samples of 14 forbs, three grasses, and three shrubs deemed important deer forages of the mesquite-mixed grass community of Welder Wildlife Refuge. CP values were similar for desirable deer forbs and shrubs, but were much lower for grasses. Values for IVDOM were greatest for forbs and lowest for shrubs. Across all plant species, CP values were moderate to good, ranging from 10 to 13% for most seasons, except in the summer and fall of 1987 when values were <9%. Values for IVDOM were typical in that digestibility declined seasonally from spring to winter. Importance values were assigned to plant species based upon selectivity by deer and nutritional content. The most important forbs were *Commelina erecta, Lesquerella lindheimeri, Nothoscordum bivalve, Ambrosia psilostachya,* and *Desmanthus virgatus. Paspalum lividum* was the most important grass, while *Zanthoxylum fagara* was the most important shrub. Because of low IVDOM values throughout most seasons, energy is a major limiting factor for deer in the Texas Coastal Bend. *Key words*: forage nutrient content; crude protein; *in vitro* digestible organic matter; white-tailed deer; *Odocoileus virginianus.*

Nutrient content of plants should be known to evaluate how well they meet the nutritional requirements of free-ranging herbivores. Most research emphasis has been given to the determination of the nutrient composition of grasses because of their importance as livestock forage. Even so, results of studies on livestock diet show that other vegetation components, such as forbs and shrubs, are used during certain seasons of the year and play an important role in supplying nutrients not provided by grasses (Hoehne et al., 1968). Furthermore, forbs and shrubs have been touted as important food items for wildlife (Chamrad et al., 1978; Bryant et al., 1979; Varner and Blankenship, 1987). Information regarding chemical composition of forb and shrub species and the dynamics of these nutrients throughout the year is limited or remains unknown in many plant communities (Huston et al., 1981).

Few studies have been conducted to determine the nutritional importance of deer food plants in South Texas. Varner and Hughes (1981) and Meyer et al. (1984) suggested that, based on the nutritional content of several classes of food plants, energy may be a limiting factor for deer during summer in South Texas. Bryant et al. (1981) reported energy also may be problematic for deer on the Edwards Plateau. Varner and Blankenship (1987) conducted a six-year study to determine the importance of shrub species in white-tailed deer, cattle, and jackrabbit diets, as well as their nutritional value and contribution to these grazing animals. Drawe (1968) found forbs to be important to deer and Everitt and Gonzalez (1979) reported that in areas of high forb availability and use by deer, their nutritional requirements were met more readily. Our objective was to determine seasonal nutrient content of 20 plant species eaten by white-tailed deer in the Texas Coastal Bend.

Methods and Materials

Study Area

The study was conducted at the Rob and Bessie Welder Wildlife Foundation Refuge. The Welder Refuge is located in the Coastal Bend ecoregion about 56 kilometers northwest of Corpus Christi, Texas. The climate of the refuge is considered subtropical with hot, humid summers and cool winters. Average annual precipitation is about 910 millimeters. Two vegetative growth peaks coincide with rainfall peaks in spring and fall. Relative humidity is high throughout the year because of the proximity to the Gulf of Mexico. The refuge has a frost-free period of 300 days and cold temperatures during winter months as low as −13°C (Drawe et al., 1978). Soils are clayey vertisols of the Victoria series (Fine, montmosillonitic, hyperthermic, Udic Pellustert), with slopes of 0-1% and are poorly drained.

The study area was located in the mesquite-mixedgrass community; one of the most extensive plant communities on the Welder Wildlife Refuge. Dominant grass species were buffalograss (*Buchloe dactyloides*), Texas wintergrass (*Stipa leucotricha*), meadow dropseed (*Sporobolus asper*), little bluestem (*Schizachyrium scoparium*), plain bristlegrass (*Setaria leucopila*), pink tridens (*Tridens congestus*), and longtom (*Paspalum lividum*). Dominant forbs included Mexican hat (*Ratibida columnaris*), western ragweed (*Ambrosia psilostachya*), sumpweed (*Iva annua*), loosestrife (*Lythrium californicum*), and clay violet (*Ruellia nudiflora*). The study area had moderate stands of shrub species such as mesquite (*Prosopis glandulosa*) interspersed with small stands of sugar hackberry (*Celtis laevigata*), huisache (*Acacia smallii*), Texas persimmon (*Diospyros texana*), lotebush (*Ziziphus obtusifolia*) and blackbrush acacia (*A. rigidula*).

Deer Diets and Chemical Analysis

Plant species included for chemical analysis were chosen based on direct observation of the foraging behavior of deer in the study area (Ortega, 1991) and from prior studies of deer diet (Drawe, 1968; Chamrad et al., 1978; Frasure et al., 1978). Fourteen forbs (three annuals and 11 perennials), three grasses (perennials), three shrubs (one evergreen and two deciduous), and mesquite beans were analyzed.

Samples of the plant species, mostly leaves, were hand-collected on a monthly basis. Samples were collected randomly from the study area for two consecutive years, July 1987 to June 1989. Because of drought conditions and seasonal rainfall pattern, not all plants were available at all times of the year.

The hand-plucked samples were oven dried at 55°C for 48 hrs and ground through a Wiley mill for laboratory analysis. Organic matter and crude protein (CP) analyses were conducted according to conventional procedures (AOAC, 1975). The *in vitro* digestible organic matter (IVDOM) determinations were carried out using the first-stage of the *in vitro* method of Tilley and Terry (1963). Two samples per month of individual species were analyzed and averaged. The study was replicated in time, not spatially, therefore our results should apply to the Texas Coastal Bend exclusively.

Plant species were grouped into forbs, grasses, and shrubs to document the quality among groups. Data were analyzed using the General Linear Method procedure of SAS

TABLE 1. Mean percent crude protein (CP) and mean percent *in vitro* digestible organic matter (IVDOM) of plant groups important to white-tailed deer, averaged across the two-year study period at the Welder Wildlife Refuge. N = number of samples in the mean. Means with the same superscript in columns are not different ($P < 0.05$). Number of plant species analyzed were: forbs = 14, grasses = 3, shrubs = 4.

Plant Group	N	CP	IVDOM
Forbs	184	11.6^{a}	48.3^{a}
Grasses	66	8.1^{b}	40.5^{b}
Shrubs	60	11.5^{a}	37.9^{b}

(1985) through a completely randomized design (Steel and Torrie, 1980) to detect differences among plant groups. Differences between means were determined by Fisher's protected Least Significant Difference procedure (P=0.05) (Ott, 1988).

Importance values for deer nutrition were assigned to each plant species. This importance value was the sum of the ranks of a selectivity index (species selected greatest ranked as 1), crude protein (species with highest percent crude protein ranked as 1), and digestibility (species with highest percent digestibility ranked as 1). The selectivity index was determined by dividing the percent use a deer made of a plant species by its percent availability (frequency). Diet and availability data were reported by Ortega (1991).

RESULTS AND DISCUSSION

Differences in both CP and IVDOM occurred among plant groups across the study period (Table 1). Forb and shrub species had similar CP and were higher in CP than grasses. Shrubs and forbs did not follow the trend found in northern latitudes where forbs have lower CP levels than shrubs (Cook, 1971).

Forbs exhibited the highest IVDOM (Table 1). No significant differences in digestibility were observed between shrubs and grasses. Forbs were roughly 8% more digestible than shrubs. These results are similar to those found by Huston et al. (1981) on the Edwards Plateau of Texas. An exception was the overall forb digestibility coefficient. In this study, IVDOM was 48%, while results from the Edwards Plateau area were greater at 54%.

Seasonally, rainfall affected the variation of CP and IVDOM across all plant groups and species. Crude protein during summer and fall 1987 were the lowest for the study period (Table 2), even though the highest May to July precipitation (530 mm) was recorded during that year (Fig. 1). The relatively high amount of rain, and possibly the high temperatures prevailing at the time, may have caused rapid maturity of the herbaceous vegetation, accelerating the maturation process toward lower quality forage when samples were taken. This may explain the low CP, as well as the low digestibility coefficients observed during these two seasons.

We attributed the significant increase in CP of important deer foods during winter of 1987 to the moisture available in November (Fig. 1),

TABLE 2. Seasonal variation in mean percent crude protein (CP) and mean percent *in vitro* digestible organic matter (IVDOM) averaged across principal plant species of importance to white-tailed deer at the Welder Wildlife Refuge. N = number of samples in the mean; Means with the same letter(s) in columns are not significantly different ($P < 0.05$).

Year/Season	N	CP	IVDOM
1987			
Summer	29	8.9 bd	42.3 bc
Fall	22	8.1 d	41.5 bc
Winter	40	10.8 b	46.7 b
1988			
Spring	24	10.8 bc	54.0 a
Summer	77	11.6 b	47.6 ab
Fall	31	13.3 a	44.8 bc
Winter	36	11.1 b	38.9 c
1989			
Spring	28	10.2 bc	42.1 bc
Summer	23	10.4 bc	39.1 c

which promoted plant regrowth under cooler temperatures. The three rainfall peaks registered in 1988 (Fig. 1), may explain the fluctuation of CP across seasons, particularly the high CP observed in the fall that coincided with September and October rains. Also in 1988, differences were found among seasons in IVDOM (Table 2). These digestibility coefficients followed a typical pattern. Highest values were observed during spring when the vegetation was growing and cell wall content was relatively low, followed by low coefficients during winter when plants were mature and had high lignin content. Generally, as vegetation matured IVDOM coefficients declined by seven, nine, and 15% from spring to summer, spring to fall, and spring to winter, respectively.

In 1989, CP values during spring and summer were similar to those found in spring 1988 (Table 2), even though the study area underwent a drought of low to moderate severity compared with the 32 year average rainfall (Fig. 1). Despite low rainfall, CP values of important deer foods were maintained during spring and summer 1989, but IVDOM coefficients were low. Wilson (1982) reported that nutritive value of vegetation may increase under low rainfall, a result similar to our findings for CP.

In general, CP of forbs important to deer was at moderate levels, fluctuating among seasons from nine to 13% (Fig. 2) but during winter, CP of forbs was relatively high, averaging 13%. Conversely, grasses had the lowest CP among plant groups across seasons (Fig. 2). Protein of grasses ranged from five to 11%. During the last three

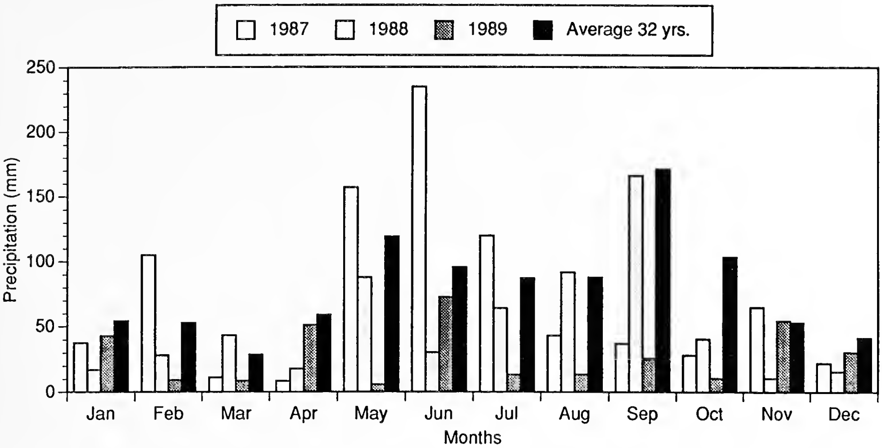

FIGURE 1. Annual precipitation (mm) recorded during 1987, 1988, and 1989, and the 32-yr monthly average at the Welder Wildlife Refuge.

seasons of 1988-89, CP of grasses was at a similar level and consistently low. This was attributed to the prevailing drought. Thus, forbs and grasses may respond differently to soil-water deficits.

CP of shrub species followed a similar seasonal pattern to that of

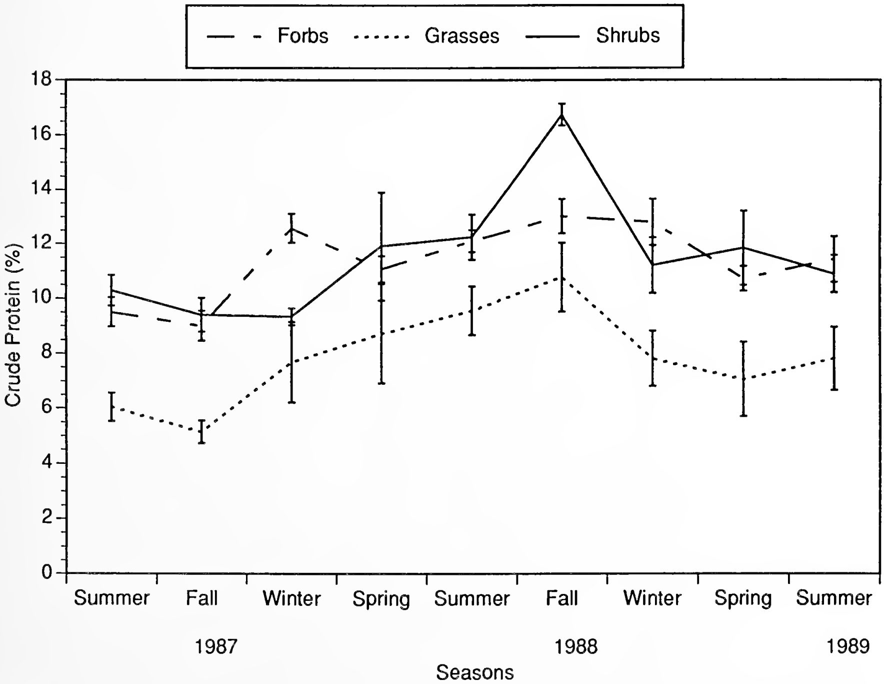

FIGURE 2. Crude protein content (%) ($\bar{X} \pm SE$) of plant groups throughout all seasons, 1987 to 1989, at the Welder Wildlife Refuge.

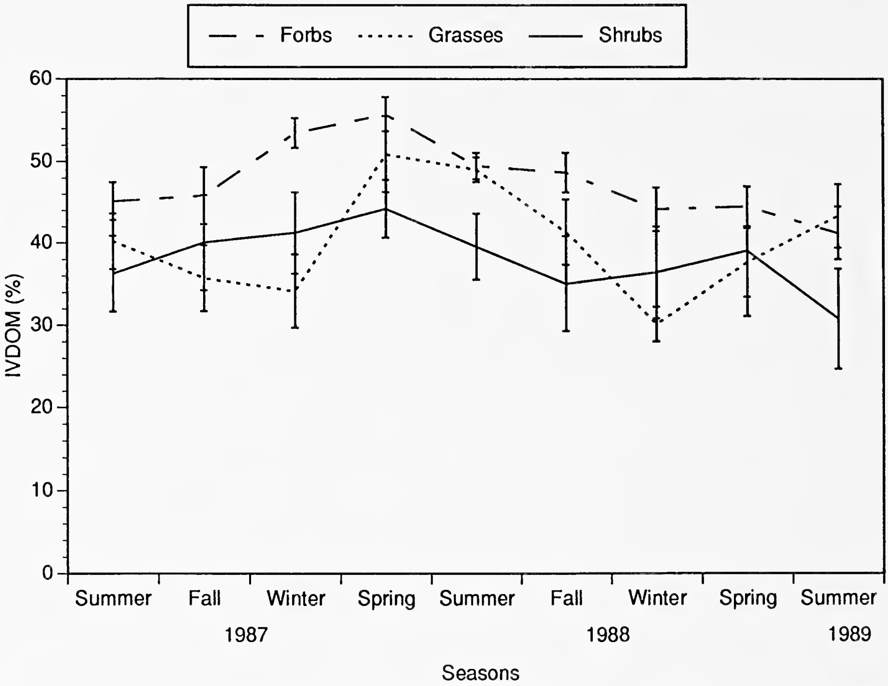

Figure 3. *In vitro* digestible organic matter (IVDOM) ($\bar{X}$ ± SE) of plant groups throughout all seasons, 1987 to 1989, at the Welder Wildlife Refuge.

forbs. CP values of shrubs and forbs were similar, with the exception of fall 1988. Shrubs had a 17% CP value compared with 13% for forbs.

In more northern latitudes, Dietz (1971) reported shrubs had higher CP than grasses and forbs during fall and winter, but lower CP during spring and summer. This was not the case in our study for most of the sampling period. Soil moisture deficit may increase quality of certain plants (Wilson, 1982), particularly herbaceous plants growing under more mesic conditions. However, relatively little is known about how nutrient content of shrubs is affected by moisture deficits.

As expected, IVDOM of plant groups across seasons followed the same trend as CP (Fig. 3). High values may be explained by the presence of moisture which promoted young, succulent and highly digestible material. Desirable deer forbs showed moderate IVDOM coefficients, ranging from 41% in winter to 57% in spring (Fig. 3). In 1987, digestibility of forbs increased in winter instead of declining. This response might be attributed to the presence of cool-season forbs or rosettes still growing during winter. Only in 1988 did forbs, as well as grasses and shrubs, follow the typical pattern of nutrient cycling (Cook, 1971), i.e., high values during spring and a gradual decline with maturity. From the end of 1988 through the middle of 1989,

TABLE 3. Percent crude protein (CP) and percent *in vitro* digestible organic matter (IVDOM) of plant species important to white-tailed deer at the Welder Wildlife Refuge. N = number of months sampled.

		CP		IVDOM	
Species	N	Mean	Peak	Mean	Peak
Forbs					
Ambrosia psilostachya	20	12.7	16.2	57.6	64.0
Commelina elegans	9	9.4	15.7	56.0	67.0
Commelina erecta	10	12.2	16.1	56.4	62.0
Desmanthus virgatus	15	12.6	17.2	35.6	41.0
Geranium carolinianum	7	11.5	13.6	48.9	62.0
Lesquerella lindheimeri	7	11.7	16.1	61.7	66.0
Lythrum californicum	19	9.2	16.2	38.7	54.0
Malvastrum aurantiacum	21	11.4	16.3	36.4	46.0
Nothoscordum bivalve	5	16.4	23.7	65.3	72.0
Oenothera speciosa	9	11.5	16.9	49.1	60.0
Oxalis dillenii	16	10.6	13.4	42.4	54.0
Ratibida columnaris	19	11.2	14.4	48.5	64.0
Ruellia nudiflora	20	11.0	15.1	51.7	60.0
Grasses					
Buchloë dactyloides	22	7.8	13.6	35.4	51.0
Paspalum lividum	21	9.7	15.9	50.0	60.0
Schizachyrium scoparium	23	6.2	13.4	36.6	52.0
Shrubs					
Eysenhardtia texana	16	11.4	17.1	27.2	53.0
Prosopis glandulosa (legumes)	6	12.5	17.4	42.0	49.0
Zanthoxylum fagara	15	11.6	16.6	54.6	70.0
Ziziphus obtusifolia	22	11.0	18.0	32.3	47.0

digestibility coefficients of desirable deer forbs were relatively low due to lack of rain and poor growing conditions. Also, IVDOM coefficients for grasses were low, particularly during winter when digestibility values were 30 to 34%. These low values are common in mature plants, a phenomenon that usually takes place during the fall and winter (Cook, 1971). Digestibility of shrub species was low (Fig. 3), with values ranging from 33 to 44%. Among all plants important to deer, shrubs showed the lowest digestibility coefficients regardless of the season and despite high CP levels.

Some species of forbs and shrubs important to deer had CP peaks of 16 to 18% and up to 70% digestibility (Table 3). High quality forbs were clay violet (*Ruellia nudiflora*), Mexican hat (*Ratibida columnaris*), and western ragweed (*Ambrosia psilostachya*). Colima (*Zanthoxylum fagara*), based on the results of this study, was the most

TABLE 4. Selectivity index (SI) and rankings of crude protein, digestibility, and importance values of plant species for deer at the Welder Wildlife Refuge. Some species were assigned the same importance value because they tied in the ranking.

Species	SI	Rank of SI	Rank of Crude Protein	Rank of Digestibility	Rank of Importance Value
Commelina erecta	9.51	1	5	4	1
Lesquerella lindheimeri	1.83	4	6	2	2
Nothoscordum bivalve	1.23	10	1	1	2
Ambrosia psilostachya	0.37	16	2	3	3
Geranium carolinianum	1.57	6	8	9	4
Desmanthus virgatus	1.59	5	3	16	5
Zanthoxylum fagara	1.18	12	7	5	5
Paspalum lividum	1.96	3	16	7	6
Oxalis dillenii	4.02	2	15	11	7
Oenothera speciosa	0.55	15	9	8	8
Ruellia nudiflora	0.89	13	13	6	8
Ratibida columnaris	1.22	11	12	10	9
Prosopis glandulosa (legumes)	0.05	18	4	12	10
Eysenhardtia texana	1.38	7	10	19	11
Lythrum californicum	1.26	8	17	13	12
Malvastrum aurantiacum	0.86	14	11	15	13
Schizachyrium scoparium	1.25	9	19	14	14
Ziziphus obtusifolia	0	19	14	18	15
Buchloë dactyloides	0.31	17	18	17	16

important shrub species in terms of CP and IVDOM. The digestibility and CP levels for lotebush (*Ziziphus obtusifolia)* and kidneywood (*Eysenhardtia texana*) were lower than those reported by Varner and Blankenship (1987) in South Texas.

When importance values were assigned, the top five plant species for deer were forbs (Table 4). Widow's tears (*Commelina erecta*) had the highest value, mostly influenced by the high selectivity of this species by deer. For different reasons, bladderpod (*Lesquerella lindheimeri*) and false garlic (*Nothoscordum bivalve*) both had the second-highest importance value. Bladderpod ranked relatively high in all parameters considered. However, false garlic had a high importance value because it ranked first in both CP and IVDOM, even though it ranked very low in deer selectivity (10th). Similarly, western ragweed (*Ambrosia psilostachya*) ranked fourth overall because of its high nutrient content (CP, 2nd; IVDOM, 3rd), but had the lowest selectivity index (Table 4). Colima (*Zanthoxylum fagara*) was the highest ranked shrub, while longtom (*Paspalum lividum*) ranked highest among the grasses.

Forbs and shrubs are important for their contribution of CP and digestibility to grazing animals in the Texas Coastal Bend. Considering that the maintenace requirement for dietary CP of adult white-tailed deer has been found to be six-10% (French et al., 1956; Dietz, 1965; Wallmo et al., 1977), CP levels found in this study can be considered as moderate to good (10 to 14%) in most seasons except summer and fall of 1987. The highest CP value (13%) of deer forages came after adequate September and October rains. In only three of nine seasons sampled IVDOM values exceeded 45%. Because digestibility affects energy supplied to deer, we agreed with the findings by Meyer et al. (1984) that energy is a major limiting nutrient for deer in the Texas Coastal Bend. Short-term droughts appear to affect energy values more than CP.

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AIR AND SOIL TEMPERATURES UNDER THREE FOREST CONDITIONS IN EAST TEXAS

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Abstract.—Air and soil temperatures on a poorly drained saline soil in the Davy Crockett National Forest near Apple Springs, Texas were monitored weekly under three forest conditions for 2.5 years. These conditions included undisturbed forest, commercial clearcutting without site preparation and clearcutting with stumps shreaded and debris windrowed. Soil temperatures were monitored at 15, 60, 90, and 120 centimeters below the surface. The mean annual air and soil temperatures were lower and the amplitudes of fluctuation were smaller in an undisturbed loblolly-shortleaf pine forest than in a sheared plot by 0.5-1.0 °C. Temperatures of the upper soil were warmer in summer and cooler in winter than that of the subsoils, and there was a time lag of about one month in maximum temperature between the top and the sub-soils. There were some inconsistencies in the temperature differences and the temperature amplitudes between the forested and cleared plots due to site characteristics and data representativeness. Low soil hydraulic conductivity, high water content, and abundant precipitation may have caused the mean annual temperatures of the saline soil to be two to three °C cooler than mean air temperture, but further tests on more saline soils are needed. The soil temperatures could be satisfactorily estimated using air temperature and time angle in a periodic regression model. Although sites with low water content tended to have high soil temperature, the inclusion of soil water content did not significantly improve the accuracy of estimates. *Key words:* saline soil; temperature; forest; East Texas.

Solar radiation received at the ground surface is dissipated into latent heat for evapotranspiration, sensible heat for warming the atmosphere, and conductive heat for soil temperature regimes. In a forest, canopies transmit only a fraction of incoming radiation to the ground surface, and at the same time they may reduce heat loss from the ground surface by longwave emission. Thus, heat exchange between ground and air is largely modified by the forest, resulting in thermal regimes within the forest that differ from those in the open.

Mean annual soil temperature (at 50 cm depth) is one of the criteria used to differentiate soil families in th U.S. soil classification system (USDA, 1975). It is also required to adjust soil salinity readings from the reference standard at 25 °C in the Martek SCT soil conductivity monitoring system (Rhoades, 1978). Soil temperature required for these purposes must be estimated if actual observations are not available. For example, the U.S. Soil Conservation Service estimates mean annual soil temperature by adding 2 °F (about 1 °C) to the mean annual air temperature (Smith et al., 1964). Dugas (1984) analyzed weekly soil temperatures at 17 Texas stations, however, land use conditions of the stations and their air temperatures were not included in the study.

A study to monitor soil, water and salt movement under three different forest conditions (undisturbed control, and two methods of clearing) was conducted on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas. Salt movements in the soil profile were examined by both laboratory analyses from periodic soil samples and *in-situ* measurements of soil electrical conductivity using the Martek SCT soil salinity bedding sensor and module system (Martek Inst. Inc., Irving, California). Soil temperatures required to adjust the salinity readings were monitored simultaneously at four different depths in a soil profile. This is a companion study of an existing project to: 1) investigate the effects of forest clearcutting and intensive site preparation on the variations of soil and air temperatures in East Texas, 2) develop empirical models for estimating soil temperature at various depths, and 3) evaluate the hypothesis that annual soil temperature is greater than annual air temperature by 2 °F (about 1 °C).

Materials and Methods

Location

The study was conducted on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas, about 200 kilometers (km) north of Houston and 250 km southeast of Dallas. The normal (1951-80) annual precipitation and temperature observed at Lufkin Airport about 22 km NE of the study area was 1,054 millimeter (mm) and 19.2 °C, respectively. The soil of the study site is Fuller fine sandy loam, a member of the fine loamy siliceous, thermic family of Albic Glossic Natraqualfs. Its salt concentration is high (total salts at 100 - 120 centimeter (cm) depth were 2933 mg L^{-1}) and drainage is extremely poor (about 6 cm hr^{-1} at the 0 - 15 cm depth). Vegetation was dominated by loblolly (*Pinus taeda*) and shortleaf (*P. echinata*) pines with scattered hardwood species. Merchantable trees were 30-55 years of age in 1988, with an average height 28.5 meter (m), DBH 25 cm, and basal area of 21.81 m^2ha^{-1}.

Treatments

There were three treatments in the study: 1) undisturbed forest with full crown closure as a control, 2) commercial clearcut with all merchantable timber removed, but other vegetation left intact, and 3) clearcut, all vegetation removed, stumps sheared with V-blade D6 crawler tractor, debris windrowed, and vegetation prevented from regrowth by shearing with no disturbance to the soil for two years. Each treatment was about 0.5 hectares (ha) in size. All three treatments were randomly located within an area of 3.24 ha with each treatment separated by a small 1st-order drainage ditch. All treatments had the same soil type and comparable environmental conditions with respect to slope and aspect. The cutting was conducted on July 23-24, and shearing on August 26, 1988.

Data Collections

Soil temperatures were monitored at 15, 60, 90, and 120 cm below the surface using an Omega digital thermometer, Model 450 and thermister sensors located in the center of each treatment plot. The sensors were mounted on wooden stakes of two cm diameter and were carefully driven into the soil. Prior to the installation, a preliminary hole of smaller diameter was first created in the soil with a steel rod to provide an easier penetration of the temperature sensors and wooden stakes. Soil temperatures were observed weekly between 12:00 p.m. and 14:00 p.m. from 15 January 1990 to 29 June 1992. Diurnal summer and winter soil temperatures were observed for 24 one-hour periods on August 19 to 20, and on December 13 to 14, 1990, respectively.

A glass-thermometer housed in a simple shelter at 1.8 m above ground in each plot monitored air temperature. *In-situ* soil moisture readings corresponding to the four depths in the soil profile were taken simultaneously using a CPN #503 Hydroprobe, a neutron scattering technique. The soil moisture readings were converted into soil moisture content in grams (g) cm^{-3} for the study site through a calibration procedure described by Ting and Chang (1985).

Soil and air temperature data collected at each site during the 2.5 years were examined for differences in means through paired t-tests. It was assumed that these data were drawn independently from a normal population and there were no significant differences of slope and aspect that would affect air and soil temperatures among the three sites. Since the treatment plots were not replicated, any statistical differences resulting from these tests only refer to those values observed at each respective site.

RESULTS

Air Temperature

Annual and monthly.—Based on 130 observations, mean air temperatures for the 2.5 years in the forested, cleared and sheared plots were 23.7, 24.2, and 24.0 °C, respectively. The amplitudes (range between peaks and troughs of the periodic cycle) were 17.6 °C for the forested, 17.7 °C for the cleared, and 18.3 °C for the sheared plots. Thus, the forested plot had both the lowest mean air temperature and the smallest temperature variation. Although the forested plot was cooler than the other two plots by only 0.5 °C, the difference was significant ($\alpha < 0.05$). The mean air temperatures of the cleared and sheared plots were not significant.

Maximum monthly afternoon temperatures all occurred in July and were 32.8 °C for the forested, 33.6 °C for the cleared, and 33.7 °C for the sheared plots. The minima (all occurred in December) were 11.4 °C for the forested, 11.8 °C for the cleared, and 11.3 °C for the sheared plots. The amplitudes of monthly fluctuation were 18.2, 18.4, and 18.9 °C, respectively for the forested, cleared, and sheared plots (Fig. 1).

Diurnal.—Hourly air temperatures during typical summer (August 19-20, 1990) and winter (December 13-14, 1990) days are shown in Fig. 2. The forest was generally the coolest during the entire 24-hour period, no matter if it were the morning, the afternoon, or the night (Fig. 2). This is inconsistent with common expectation that ambient temperature in the cleared site is warmer during the day and cooler at night than that of a forested site (Lal and Cummings, 1979).

On the summer day, the mean temperature for the undisturbed forest was 28.1 °C, or about 1.5 °C cooler than the cleared, and 1.2 °C cooler than the sheared areas. Maximum temperature was 36.7 °C at 4 p.m., 38.9 °C at 3 p.m., and 36.7 °C at 5 p.m. for forested, cleared, and sheared plots, respectively. All miniumum temperatures occurred at 7

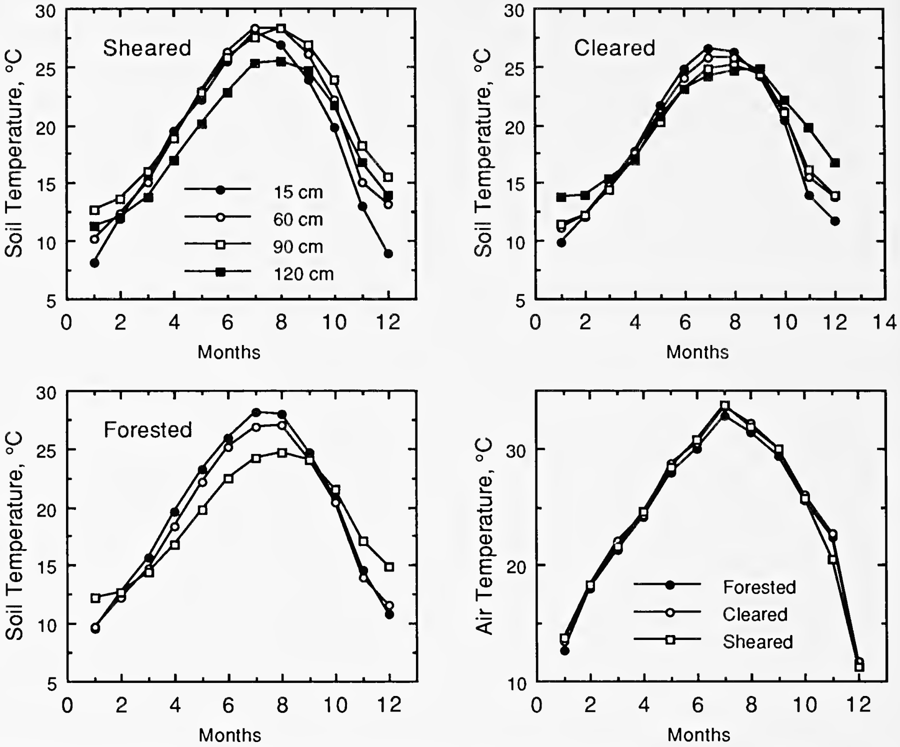

FIGURE 1. Mean monthly soil and air temperatures for three forest conditions (forested, sheared, cleared) on a saline soil in the Davy Crockett National Forest near Apple Springs, Texas.

a.m.; they were 21.1 °C in the forested and 22.2 °C in the cleared and sheared areas. The amplitudes of the 24-hour period were 13.8, 15.0, and 13.2 °C for the three respective treatment areas. The commercial clearcut area was not expected to have the greatest maximum temperature and the greatest temperature fluctuation.

On the winter day, the mean temperature for the forested plot was 14.8 °C, or 1.1 °C and 1.6 °C cooler than that for the cleared and sheared plots, respectively. Every possible difference in temperature mean among the three treatments was significant at the 0.05 level. But, maximum and minimum hourly temperatures were reached much earlier on the winter day than on the summer day. Maximum temperatures (all at 2 p.m.) were 25.6 °C for the forested plot, and 26.7 °C for the cleared and sheared plots. Minimum temperatures were 10.0 °C at 2 a.m. for the forest, and 11.1 °C at 4 a.m. for the cleared and sheared plots. However, the cleared plot had the smallest amplitude (11.6 °C), followed by sheared (12.1 °C) and forested (12.6 °C) plots.

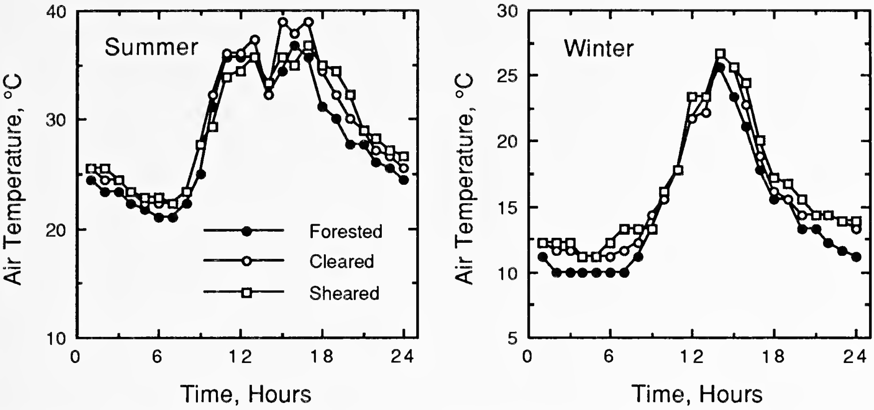

FIGURE 2. The hourly air temperatures on a typical summer (August 19-20, 1990) and winter (December 13-14, 1990) day for three forest site conditions (forested, cleared, sheared) near Apple Springs, Texas.

Soil Temperatures

Annual and monthly.—Mean temperatures in the soil profile (15-90 cm) for the 2.5-year study period were 18.7, 18.4 and 19.5 °C for the undisturbed forest, cleared, and sheared plots, respectively. These mean soil temperatures were lower than mean air temperatures by 4.7 °C for the forested, 6.2 °C for cleared and 5.2 °C for sheared plots. Although the sheared area was warmer than the forested plot by only 0.8 °C and the cleared plot by 1.1 °C, paired t-tests showed that the means between any pair of treatments were significantly different ($\alpha < 0.05$). The differences between treated and untreated plots would have been much greater if the comparisons were made for temperatures monitored at the ground surface (Fowler et al., 1987; McGee, 1976; Swank and Vose, 1988).

Soil temperatures regimes are mainly affected by solar irradiation, heat exchange between soil and air, vegetation, and thermal properties of the soil. Thus, surface temperature closely follows ambient air temperature, while the amplitude of temperature waves decreases with increasing depth until it is completely damped out at a certain level. In the study area, the amplitude at 15 cm depth was 17.6 °C for the forested, 16.3 °C for the cleared, and 18.3 °C for the sheared plots. The amplitude was reduced to 12.4, 13.7, and 15.3 °C (in that same order) at the 90 cm depth. The amplitudes were always greatest in horizons close to the surface and in the sheared plot where vegetation and debris were completely removed from the site. There was a great deal of variation in the amplitudes of temperature waves between the undisturbed forest and the commercial clearcut sites.

The amplitude (A_z) of soil temperature wave decreases with depth z and can be estimated using the amplitude at the surface (A_o) in accordance with the function (Rose, 1966):

$$A_z = A_o \exp[-z(w/2k)^{0.5}]$$

where w is the angular frequency of the surface temperature or $w = 2\pi/t$ where t is the period of surface temperature fluctuations (i.e., 86,400 seconds for the daily wave) and k is the thermal diffusivity in cm^2sec^{-1}. Thus, the corresponding value of z for the annual wave is about $(365)^{0.5}$, or 19 times deeper than that for the daily wave. If the daily isothermal level for the forested area is 90 cm in the summer (Fig. 1), then the annual level would be about 17.1 m below the surface. Differences in annual isothermal depth at this depth among treatments are not important for forestry activities.

On the monthly fluctuations, temperatures in the upper soil were generally warmer in summer and cooler in winter months than that in the subsoil. The so-called temperature "overturn" in the soil profile occurred in late March and September. At the surface 15 cm depth, all the maximum temperatures of the three treatments occurred in July and the minimum occurred in January. At the 90 cm depth, all the maximum monthly temperatures for the three areas occurred in August. Heat transfer processes caused a time lag of about one month between maximum air temperature and the maximum soil temperature at the 90 cm depth.

Differences in July temperatures within each soil profile (15-90 cm) were 3.9 °C, 1.8 °C, and 0.4 °C for the forested, cleared, and sheared plots, respectively. But in January the differences were 2.6 °C, 1.6 °C, and 4.5 °C, in that order. Thus, the greatest temperature difference within the soil profile occurred in the forested plot in summer, and the sheared plot in winter (Fig. 1).

Diurnal.—Hourly soil temperatures observed in a typical summer and winter day for the three forest site conditions are shown in Fig. 3. The diurnal temperature fluctuation was smaller and the isothermal levels were shallower for the summer day than for the winter day. On the summer day, the average temperature for the whole profile (15-90 cm) was warmest in the sheared plot (28.8 °C), followed by the forested (27.5 °C) and cleared (26.5 °C) plots. However, using Scheffe's method (Ott, 1988) of multiple comparisons showed that the means below 15 cm depth differed significantly between any pair of the three treatments ($\alpha < 0.05$).

The summer-day minimum soil temperature at the 15 cm depth occurred at 9 a.m. for the forested (25.4 °C) and sheared (24.5 °C) plots, and at 10 a.m. for the cleared (25.9 °C) plot, a lag of about two to three hours from the air temperatures. After the minimum, the 15 cm depth soil temperature rose along with air temperature, reaching a maximum

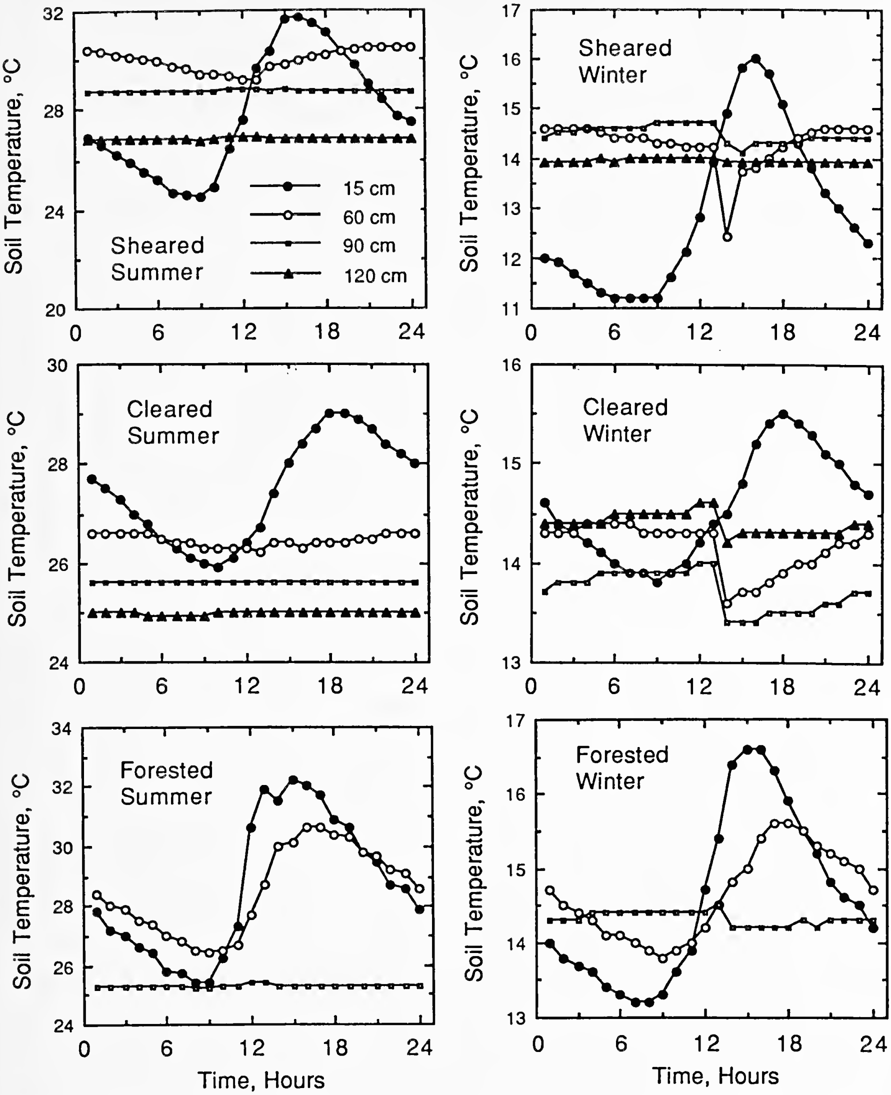

FIGURE 3. The hourly soil temperatures on a typical summer (August 19-20, 1990) and winter (December 13-14, 1990) day for three forest site conditions (forested, cleared, sheared) near Apple Springs, Texas.

at about 3 p.m. for the forested (32.2 °C), 6 p.m. for the cleared (29.0 °C), and 4 p.m. for the sheared (31.7 °C) plots. Soil temperature declined more slowly from its maximum than did air temperature. Soil temperature remained higher than air temperature for 15, 11, and 12 hours for the forested, cleared, and sheared plots, respectively. The longer duration for night time soil temperature to be warmer than air temperature in the forested plot is a response to the effects forest canopy and litter have on emission of longwave radiation at the ground surface. Essentially constant temperature occurred at 90 cm or greater depth below the surface. However, the summer soil temperature at the 15 cm (and the 60 cm) level of the forested plot was unexpectedly warmer than that at the corresponding level of the cleared plot.

On the winter day (December 13-14, 1990), average hourly soil temperatures were highest in the forested plot (14.5 °C), followed by the cleared (14.2 °C) and sheared (13.9 °C) plots. Statistical analysis showed that the soil temperatures at the 15 and 60 cm depths of the sheared plot were significantly cooler and the temperature at the 90 cm depth was significantly warmer than that of the forested plot ($\alpha < 0.05$).

Minimum soil temperatures at 15 cm depth occurred at 7-8 a.m. for the forested plot (13.2 °C), 9 a.m. for the cleared plot (13.8 °C), and 6-9 a.m. for the sheared plot (11.2 °C). Conversely, maximum soil temperatures occurred at 3 p.m. (16.6 °C), 6 p.m. (15.5 °C), and 4 p.m. (16.6 °C) for the three respective site conditions. These minimum soil temperatures were higher and maximum soil temperatures were lower than air temperatures. For the 24-hour period, there were 16, 13, and 2 hours, in the same order, in which soil temperatures were warmer than air temperatures. However, the average hourly soil temperatures at the 15 cm depth were colder than the air temperatures by 1.5 °C (sheared) to 0.2 °C (forested). The depths at which soil temperature was constant were deeper on the winter day than on the summer day.

Soil Temperature Prediction

Assuming basic soil properties are constant and surface conditions are relatively stable, then soil temperature (T_s) for any day of a year t starting with January 1 as 001 can be referenced to ambient temperature (T_a) and time angle in its annual cycle by:

$$T_s=B_0+B_1T_a+B_2\mathrm{Cos}(2\pi t/365)+B_3\mathrm{Sin}(2\pi t/365)+E$$

where B_0, B_1, B_2, and B_3 are regression coefficients, $(2\pi t/365)$ are daily units of time angle in the annual cycle measured in radians, and E is the error term of the prediction. The coefficients of the equation, along with predictabilities for estimating the soil temperature data under the three forest site conditions during the 2.5-year period, are given in Table 1. The equation fits the soil data well with values of R^2 0.91 or greater (except 0.78 for the cleared plot at 120 cm depth) and standard error of estimates less than 2.1 °C. The standard errors of the estimate decrease with depth in agreement with decreasing temperature with depth and greater temperature fluctuations at the surface. However, the effect of air temperature decreased with increasing depth

TABLE 1. Coefficients and statistics of the periodic equation** developed for estimating soil temperatures for a saline soil in East Texas. S.E.E. = standard error of estimate.

Treatment/Depth, cm	B_0	B_1	B_2	B_3	R^2	S.E.E.
Forested, 15	9.490	0.417	-4.708	-1.999	0.91	2.1
60	12.337	0.273	-5.307	-2.634	0.91	2.0
90	17.876	0.036	-4.368	-3.998	0.95	1.0
Cleared, 15	13.154	0.227	-5.404	-2.914	0.91	1.8
60	16.717	0.093	-5.357	-3.723	0.94	1.3
90	16.999	0.069	-4.925	-3.844	0.94	1.2
120	20.019	-1.012*	-3.996	-4.099	0.78	2.1
Sheared, 15	7.033	0.477	-4.472	-1.674	0.92	2.1
60	16.528	0.140	-6.538	-3.882	0.94	1.6
90	19.969	0.036*	-5.807	-4.459	0.94	1.4
120	16.860	0.077	-4.818	-4.261	0.93	1.4

* Not significant at the 0.05 alpha level.

** $Ts = B_0 + B_1Ta + B_2 \cos(2\pi t/365) + B_3 \sin(2\pi t/365)$, where Ts and Ta are soil and air temperatures (in °C), respectively, t is the observational period starting from January 1st, $(2\pi t/365)$ are daily units of time angle within a single annual cycle measured in radians, and B_0, B_1, B_2, and B_3 are regression coefficients.

and was insignificant at 120 cm depth in the cleared plot and at 90 cm depth in the sheared plot. This indicates that the soil temperature regime in the subsoils is largely influenced by heat capacity and heat transfer processes.

Soil water content affects soil heat transfer processes through evaporation (latent heat), specific heat (about 0.75 cal g^{-1} $°C^{-1}$ greater than soils), and thermal conductivity and diffusivity. Analysis of the first year data showed that soil temperature correlated negatively with soil water content with correlation coeffcients ranging from -0.008 to -0.614 (Juin, 1991). The coefficients were generally greater at deeper soil levels and for the sheared plot. However, inclusion of soil water content in the equation did not significantly improve the predictability for the data collected in the first year study. Consequently, it was not retained in the model for this study.

DISCUSSION

Since air and soil temperature measurements were made every Monday at 12:00-14:00 p.m. (except for diurnal observations), they should be referred to as afternoon temperatures. Information on morning or night time temperatures are not available in this study. However, judging from the hourly temperatures monitored during the two typical days in summer and winter, the mean annual and monthly soil temperatures at the 15-60 cm depth could have been overestimated by 1-2 °C. Overestimates of air temperature could range from 3-6 °C.

The soil temperature is related to air temperature by many complex interactions (Chang, 1968). Smith et al. (1964) stated: "The mean annual soil temperature is higher than the mean annual air temperature over most of the United States. The difference is usually about 2 °F in the humid Southern and Central States...". They further indicated that the soil temperature referred to was for 50 cm depth. The average soil temperature is "1-5 °K" warmer than the air temperature in Canada (Lewis and Wang, 1992). In this study, the mean annual soil temperatures at the 60 cm depth were cooler than the annual air temperatures by 5-6 °C under each of the three forest conditions. Considering the overestimates of mean annual air and soil temperatures, mean soil temperatures in the study area may be cooler than mean air temperature by 2-3 °C. This result contradicts both Smith et al.'s (1964) report and Chang's (1977) study on a Shubuta soil in the Stephen F. Austin Experimental Forest, Nacogdoches, Texas, about 50 km NE of this study area. Like the saline (Fuller) soils, the Shubuta soils are sandy loams supporting a mixed stand of loblolly-shortleaf pines with scattered hardwoods, but the mean annual soil temperature was warmer than the mean annual air temperature by 1.4 °C. Factors such as low hydraulic conductivity and high soil water content of the saline soil along with exceptionally high precipitation during the study period may have caused the soil temperature to be cooler than the air temperature.

The average saturated hydraulic conductivity determined in the laboratory was 6.01 cm hr^{-1} at the 0-15 cm depth, much slower than 71.01 and 17.70 cm hr^{-1} at the 0-7.5 and 7.6-15.2 cm depths, respectively, reported for a Rains soil of similar texture in the Lower Coast of North Carolina (Sayok, 1991). The average soil water content during the first year of the study period was 0.205, 0.187, and 0.252 g cm^{-3} for the forested, cleared, and sheared plots, respectively. These water contents correspond to a suction of about 33 kPa on the soil water retention curves (Sayok, 1991). Such water contents favored evaporation/transpiration which cooled the soil and kept surface temperature fluctuation small. The cool soil temperature could also be induced by frequent showers and rainstorms in the warmer seasons. Annual precipitation recorded in 1990 and 1991 at the study site was 1,542 mm and 1,377 mm, respectively, compared with the normal annual precipitation (1951-80) of 1,054 mm recorded at Lufkin Airport.

The result that mean annual soil temperatures were cooler than mean annual air temperatures are of particular interest, but must be considered with caution because this was not a replicated study. The results apply only to the study site and should be further tested on more saline soils. If it is real, then the growing season, seed germination, and root development in the saline soil may be affected.

In a controlled environment, the root dry weight of eight week-old paper birch (*Betula papyrifera*) was 57 milligrams (mg) when soil temperature was 15 °C, but it increased to 436 mg when soil temperature was 19 °C (White et al., 1975). Cooler soil temperatures within the optimum range mean lower biological activities, lower decomposition rates of organic matter, and consequently fewer nutrients available to plants. Any hydro-climate models that simulate soil temperatures, soil respiration, or decomposition rates of soil organic matter in saline soils based on the standard air temperature conversion method (i.e., added 1 °C) would be erroneous in their projections.

There were some inconsistencies in the temperature differences and temperature fluctuation between the forested and cleared plots. For example, the forested plot had a greater annual mean soil temperature and a greater mean hourly soil temperature on the typical summer day than the cleared plot. The drier soils in the cleared plot may have been a factor in this. Also, the maximum air temperature and temperature fluctuation were greatest in the cleared plot on the typical summer day. A tornado occurred on January 20, 1990 damaging 50% canopy of the forested plot which may contribute to part of the discrepancy in the present study. It also indicates that heat dissipation and transfer processes are extremely complicated in areas surrounding by forest canopies, trunks, understory vegetation, litter and organic matter on the forest floor. Measurements made from a single site may not be representative for the entire area.

In southwest Oregon, shelterwoods lowered August and September soil temperature at the two and 32 cm depths on south-facing slopes by 6 °C when compared with cleared sites (Childs et al., 1985). In summer, soil temperatures at the 5 to 40 cm depths averaged about 5-7 °C warmer in the clearcut broadcast burn than the uncut forest in the Gros Ventre Mountains of Wyoming (Hungerford and Babbitt, 1987).

CONCLUSIONS

Mean annual air and soil temperatures were lower and the amplitudes of fluctuation were smaller by 0.5-1.0 °C in the forested plot than the sheared plot in keeping with less incident solar radiation reaching the ground through the canopies and litter in the forested site and lowered longwave emission. Temperatures of the upper soil were warmer in summer and cooler in winter than that of the subsoil. The temperature "turn-over" occurred in late March and September, and there was a time lag of about one month for attaining maximum temperature between the top- and sub-soils.

Hourly air temperature in the forested plot was generally the coolest of the three plots, in the morning, the afternoon, at night, or during the typical summer and winter days. For the mean hourly soil temperature, the sheared plot was the warmest on the summer day and the coolest in the winter day among the three treatments. However, site characteristics and data representativeness may have caused some of the differences of air and soil temperatures and temperature fluctuations between the forested and cleared plots to be inconsistent in this study.

The single measurements of air and soil temperatures at 12:00-14:00 p.m. on every Monday may have overestimated the mean annual soil temperatures by 1-2 °C and the mean annual air temperatures by 5-6 °C. Due to the extremely slow soil hydraulic conductivity, near saturated soil water conditions and exceptional abundance of precipitation during the study period, mean annual soil temperatures in the three treatment areas were cooler than mean annual air temperatures by 2-3 °C. Because of lack of replicates, this result, contradictory to Smith et al.'s (1964) report, requires further tests on more saline soils.

The fluctuation of soil temperature could be empirically estimated using air temperature and time angle in a periodic regression analysis with standard error of estimate less than 2 °C. Although soil temperature is negatively correlated with soil water content and sites with low water content tend to have high soil temperature, the inclusion of soil water content did not improve the predictability of the developed models. The effects of air temperature on soil temperature decreases with increasing soil depth. In the subsoil, soil temperature is mainly affected by soil heat capacity and heat transfer processes.

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REVISION OF THE SUBGENUS *POLYATAX* (ACARI: UNIONICOLIDAE: UNIONICOLINAE: *UNIONICOLA*)

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Abstract.—More than 45 subgenera are recognized within the genus *Unionicola.* The subgenus *Polyatax* Viets contains 14 water-mite species from the Northern Hemisphere. All of these species parasitize freshwater mussels or snails. Herein, *Polyatax* is divided into six subgenera, which represent six distinctive groups, and four new subgenera are erected: *Breaudatax, Causeyatax, Clarkatax,* and *Imamuratax.* The subgenus *Neoatax* Lundblad is resurrected. *Key words*: *Unionicola; Polyatax*; new subgenera, *Neoatax, Breaudatax; Causeyatax; Clarkatax; Imamuratax;* taxonomic revision.

More than 45 subgenera are recognized within the genus *Unionicola* Haldeman, (Smit, 1992; Vidrine, 1992a, b; Vidrine, 1993). The subgenus *Polyatax* Viets 1933 (Acari: Unionicolidae: Unionicolinae: *Unionicola*) includes a diverse collection of water-mite species. Seven of the 14 species in the subgenus were recently described (Vidrine, 1985 a, b). The subgenus has been re-evaluated several times (Viets, 1957; Cook, 1974; and Vidrine, 1985b, 1986). Vidrine (1985b, 1986) synonomized the subgenus *Neoatax* Lundblad with *Polyatax.*

Probably, the entire group represents a radiation from a single ancestral group within *Unionicola.* However, the female acetabular plates are diverse and, apparently, all are the type used for ovipositing into mantle tissue of their hosts. Other characters, including morphology of the venter and dorsum, varied kinds of sexual dimorphism in the walking legs of the males, chaetotaxy of legs, and morphology of pedipalps, legs and tarsal claws, indicate that six distinctive groups have developed to an extent that named taxa should be erected. Divergence within the subgenus *Polyatax* exceeds that accepted in most other subgenera. Consequently, this paper redefines *Polyatax*, creates four new subgenera, and resurrects the subgenus *Neoatax* Lundblad.

Methods

Specimens of the subgenus *Polyatax* in my collection were re-examined, since the ranges of morphological variation, host groups, and behavior among these species exceeded those accepted for species within other single subgenera of the genus. The species were grouped based on similarities and were separated based on observed differences. Resultant groups are herein designated as subgenera, redescribed, and/or described for the first time.

RESULTS

Subgenus *Polyatax* Viets 1933

Type species.—U. japonensis Viets 1933.

Diagnosis.—Genital acetabula many pairs; female genital field with two pairs of acetabular plates; anterior female plates with an elongate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate modified with many acetabula; pedipalp subcylindrical and well-sclerotized with tarsus usually nearly quadrate in outline with large, obvious clawlets; most species with obvious dorsal plates; male genital field as in *Pentatax* Thor; first walking legs with large prominent setae; male fourth walking leg modified in some species; tarsal claws of walking legs deeply bifid in some species; coxal plates with obvious borders.

Habitat.—Parasites of snails (Viviparidae).

Distribution.—Asia and North America.

Discussion.—Studied species of *Polyatax* oviposit in the mantle and foot epithelia of their hosts. The snail mites now include three subgenera: *Polyatax* in Asia and North America, *Ampullariatax* Vidrine 1985b in Central and South America, and *Baderatax* Vidrine 1988 in Africa. Species of *Polyatax* are adequately illustrated in Imamura (1953), Marshall (1935) and Vidrine (1985b).

Additional species included.—Unionicola campelomaicola Marshall, 1935, *U. dobsoni* Vidrine, 1985b, and *U. viviparaicola* Vidrine, 1985b.

Subgenus *Imamuratax* new subgenus

Type species.—U. scutigera Viets 1926.

Diagnosis.—Genital acetabula many pairs; female genital field with two pairs of acetabular plates; each anterior female acetabular plate with a very elongate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate modified and resembling that of *Polyatax*; pedipalp subcylindrical and well-sclerotized with tarsus rectangular and somewhat elongate with large, obvious clawlets; dorsum with obvious dorsal plates; male genital field as in *Polyatax*; male fourth walking leg apparently unmodified; bifid tarsal claws in all walking legs, while tarsal claws of second and third walking legs are obviously bifid to a lesser degree than those of the first and fourth walking legs; coxal plates with indistinct borders.

Habitat.—Parasites of mussels (Unionidae). Despite several reports of *U. scutigera* in snails in the literature (Gledhill, 1985), the source (Viets, 1926) clearly reports it from mussels of the genus *Lamellidons* (sic). No host was reported for this mite in Viets and Plate (1954).

Distribution.—Asia.

Discussion.—This is a group of mites that is distinctive with coxal plates lacking obvious borders and extremely elongate, spinous flaps on anterior female acetabular plates. Species are adequately illustrated in Viets (1926, 1957) and Vidrine (1985a).

Additional species included.—Unionicola heardi Vidrine, 1985a, and *U. neokoenikei* Viets, 1957.

Subgenus *Neoatax* Lundblad 1941

Type species.—U. indistincta (Wolcott 1898).

Diagnosis.—Genital acetabula three to many pairs; female genital field with two pairs of acetabular plates; anterior female plates with an elognate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate modified and resembling *Polyatax,* but with fewer acetabula; coxal plates variable, with one species, *U. abnormipes,* lacking obvious borders; pedipalp subcylindrical and well-sclerotized with tarsus usually nearly quadrate in outline with large, obvious clawlets; dorsum with obvious dorsal plates; male genital field as in *Polyatax;* male fourth walking leg modified with tibia bearing one or two large blunt spines; tarsal claws of walking legs bifid; first walking legs with large setae.

Habitat.—Parasites of mussels (Unionidae).

Distribution.—North America.

Discussion.—This subgenus is rather uniform in that the fourth walking legs of the males are very similarly modified in each of the species. Resurrection of this subgenus, as it represents a separate group, is necessary. Species are adequately illustrated in Wolcott (1898, 1899) and Vidrine (1985b). Downes (1991) has studied the ecology of *U. abnormipes.*

Additional species included.—Unionicola abnormipes (Wolcott, 1898), *U. australindistincta* Vidrine, 1985b, and *U. causeyae* Vidrine, 1985b.

Subgenus *Causeyatax* new subgenus

Type species.—U. hensleyi Vidrine 1985b.

Diagnosis.—Genital acetabula five pairs; female genital field with two pairs of acetabular plates; anterior female plates with a slightly elongate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate unmodified; pedipalp subcylindrical and well-sclerotized with tarsus usually elongate quadrate in outline with large, obvious clawlets; dorsum with obvious dorsal plates; male genital field as in *Polyatax;* male fourth walking leg modified, especially genu, but the tibia is essentially unmodified; tarsal claws of walking legs bifid; coxal plates with obvious borders.

Habitat.—Parasites of mussels (Unionidae).

Distribution.—North America.

Discussion.—This subgenus is closely related to *Neoatax*, but the distinctive leg modifications in the fourth walking leg of the males require its placement into a separate group. The species is adequately illustrated in Vidrine (1985b).

Subgenus *Clarkatax* new subgenus

Type species.—*U. serrata* (Wolcott 1898).

Diagnosis.—Genital acetabula many pairs; female genital field with two pairs of acetabular plates; anterior female plates with an elongate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate modified with many acetabula; pedipalp subcylindrical and well-sclerotized with tarsus usually nearly quadrate in outline with large, obvious clawlets; dorsum with obvious dorsal plates; male genital field as in *Polyatax*; male and female legs similar; tarsal claws of walking legs bifid; coxal plates with distinctive borders.

Habitat.—Parasites of mussels (Unionidae).

Distribution.—North America.

Discussion.—This species has numerous serrated spines. The nymphs are unusual in having three to five pairs of genital acetabula. This species lives in the area of the labial palps of their hosts. The species is adequately illustrated in Wolcott (1899). Downes (1991) and Mitchell (1965) studied the ecology of this species.

Subgenus *Breaudatax* new subgenus

Type species.—*U. megachela* Vidrine 1985b.

Diagnosis.—Genital acetabula five pairs; female genital field with two pairs of acetabular plates; anterior female plates with an elongate, inner flap that is heavily sclerotized and bears one or two, short, thick, spinous, setae; posterior female plate unmodified; pedipalp subcylindrical and well-sclerotized with tarsus miniscule but bearing large, obvious clawlets; dorsum with obvious dorsal plates; male genital field as in *Neoatax*; male fourth walking leg slightly modified with genu and tibia with enlarged dorsal spines; first walking leg with short, thick setae and similar in both sexes; tarsal claws of walking legs very large and simple.

Habitat.—Parasites of mussels (Unionidae).

Distribution.—North America.

Discussion.—This species lives in the area of the labial palps of its hosts. It has numerous serrated spines and unique tarsal claws and leg structure. The modifications in the fourth walking legs of the males are much less obvious than in *Neoatax*, however, these are yet apparent. Its pedipalps closely resemble those of *U. causeyae.* The species is adequately illustrated in Vidrine (1985b).

Discussion

The subgenus *Polyatax* contained a diverse collection of water-mite species, which apparently oviposit in the mantle tissues of their freshwater mussel and snail hosts. The separation of the subgenus into six subgenera provides for the separate placement of groups of species that apparently diverged rather early in the evolution of this ancient lineage in the genus. These mites are derived from a single ancestral group, but the subgenera that exist today are ancient, and each is the result of a long line of evolutionary events. The characters used to separate these subgenera are well in line with those used to separate other subgenera in this genus.

Among the subgenera, *Polyatax* appears to be the most ancient group. It includes parasites of snails in Asia and North America, whereas the other subgenera contain parasites of mussels. The mussel parasites appear to have split early and produced the Asian subgenus *Imamuratax.* The remaining four subgenera are the North American representatives, which apparently later split into two groups. One group contains *Neoatax* and *Causeyatax,* while the other contains *Clarkatax* and *Breaudatax. Neoatax* and *Causeyatax* live on the mantle of their hosts, but *Neoatax* has very distinctive sexual dimorphism in the fourth walking legs of the males and is apparently restricted to the United States and southern Canada. *Causeyatax,* with its own distinctive sexual dimorphism, is only known from northern Mexico. *Clarkatax* and *Breaudatax* reside between the labial palps of their hosts. *Clarkatax* apparently lacks obvious sexual dimorphism in the walking legs, while *Breaudatax* has moderate, but obvious sexual dimorphism in the fourth walking legs of the males.

Are the snail mites of the world closely related? Three subgenera of *Unionicola* can be considered host-specific to freshwater snails. *Polyatax* occurs in viviparid snails in Asia and North America. *Baderatax* occurs in pilid snails in Africa (Gledhill, 1985; Vidrine, 1988). *Ampullariatax* occurs in pilid snails in Central and South America (Cook, 1974; Vidrine, 1985b). While all three subgenera bear resemblance to *Pentatax* Thor, each is unique. *Polyatax* and *Baderatax* share the greatest number of derived characters, and *Ampullariatax* is quite distantly related. Occasionally, members of *Pentatax* occur in snails as well as mussels (Böttger, 1972), and this condition may be ancestral to the divergence and possibly led to the development of parasitic mite-snail relationships as found in these three subgenera.

Are mantle mites of the world closely related? Nine subgenera are now included in this group. All of these oviposit in mantle tissue of their molluscan hosts. Most divergent from the subgenera treated in this paper are the subgenera *Anodontinatax* Vidrine and *Vietsatax* Uchida and Imamura (Vidrine, 1986). These latter two subgenera are host-specific for anodontine mussels of the Northern Hemisphere and bear a strong resemblance to the subgenus *Pentatax*. No mantle mites are presently known from mussels of the Southern Hemisphere. *Pentatax* is restricted to the Northern Hemisphere (Vidrine, 1988) and contains mites that are generally free-swimming and only return to host mussels and snails to oviposit and undergo metamorphosis. I suspect that mantle mites represent two entirely separate divergences: one in the snails and amblemine mussels and the other in the anodontine mussels. A case could be made for three divergences if the snail mites diverged early and underwent sufficient parallel evolution with the amblemine mussel mites.

Polyatax and her sister subgenera apparently represent an impressive adaptive radiation. Unfortunately, little is known of the ecology and natural history of these mites. Hosts and distributions have been discussed (Vidrine, 1985a,b, 1989, 1990; Vidrine and Wilson, 1991). Downes (1991) discussed the behavior of two species of these mites in patchy environments. Few of the species have been studied in any detail, and this paucity of information is in part due to the lack of fundamental hypotheses regarding their systematics. The restructuring of this collection of species into a new hierachy provides a number of testable hypotheses.

Acknowledgments

Specimens of water-mites belonging to these subgenera and related subgenera were sent to me by D. R. Cook and T. Gledhill. The new subgenera were named to honor the following: D. R. Clark, T. P. Breaud, T. Imamura, and the late N. B. Causey.

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WHEWELLITE ROCK CRUSTS IN THE LOWER PECOS REGION OF TEXAS

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Abstract.—The Lower Pecos region of Texas contains some of the most outstanding prehistoric rock paintings found in the New World. Covering the paintings is a natural rock crust that may play an important role in preserving these artifacts. We have determined that the rock crust is composed primarily of calcium oxalate in the mineral form whewellite. The origin of the whewellite is unknown. *Key words*: whewellite; calcium oxalate; rock crusts; rock art.

The Lower Pecos region of Texas, generally described as the area surrounding the confluences of the Pecos and Devils rivers with the Rio Grande (Fig. 1), contains one of the longest continuous records of human occupation in North America (Turpin, 1982). Evidence indicates that people began inhabiting rock shelters in the region about 9,000 years ago and remained until historic times (Hester, 1983). Part of the legacy of these ancient Texans is the extraordinary prehistoric rock paintings (pictographs) found in over 250 rock art sites. The most impressive and oldest pictographs are the large, polychromatic Pecos River style pictographs. These artifacts have been reported to be between 3,000 and 4,200 years old, based on radiocarbon dating of organic matter in the paint (Russ et al., 1990; Russ et al., 1992a) and population density (Turpin, 1990). The longevity of the pictographs may be due to the naturally occurring crusts that form on the back wall of the dry rock shelters and cover the paintings. Here we report that this crust is composed primarily of calcium oxalate in the monohydrate mineral form whewellite ($CaC_2O_4 \cdot H_2O$).

Whewellite has been reported as rare in the geological environment (Graustein et al., 1977; Zák and Skála, 1993), but recently it has been identified on quartzite and sandstone rock faces in Australia (Watchman, 1990) and on marble and calcareous limestone monuments, historical buildings and natural outcrops in Italy (Del Monte et al., 1987; Seaward et al., 1989). The origins of whewellite in these environments is still unknown; proposed mechanisms for its production include metabolic activity of encrusting lichen (Del Monte et al., 1987) and organic acids in rain water reacting with calcium-rich dust (Watchman, 1990). Radiocarbon dating experiments of the oxalate-rich crusts in Australia led Watchman to suggest that the crusts

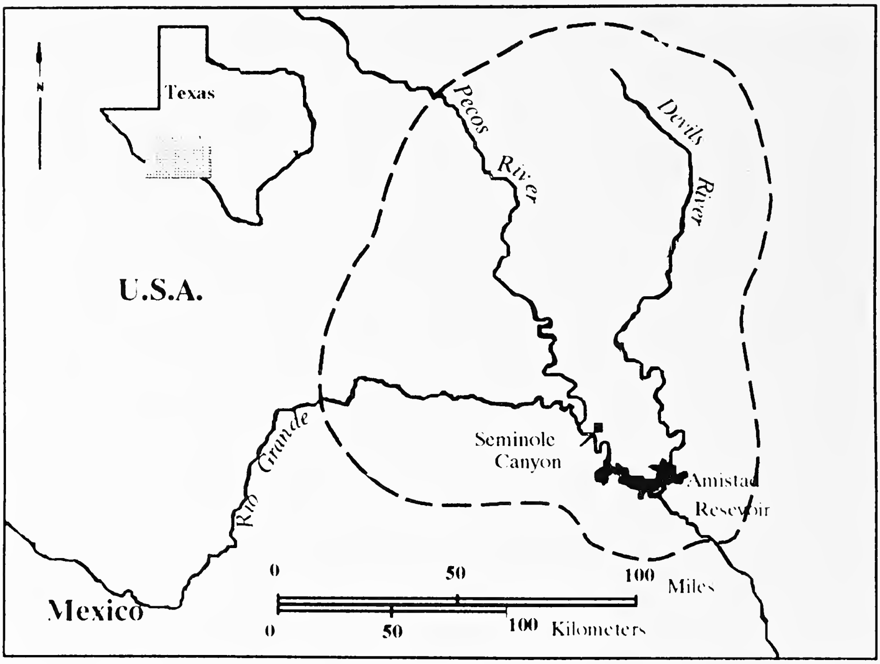

Figure 1. Map showing approximate extent of the Lower Pecos region.

may be useful as chronological and paleoenvironmental indicators (Watchman, 1991).

In the Lower Pecos, two distinct forms of rock accretions cover the limestone rock surfaces: a dark gray to black rock varnish coats areas that are directly exposed to rain and rain run-off while a light brown crust forms in more sheltered areas. Since the majority of the pictographs are in dry rock shelters, it is the light brown crust that covers the artifacts. This material is translucent, allowing the prehistoric paint to show through, though giving them a "faded" appearance. Zolensky (1982) identified the mineralogy of various pigments used in some of the prehistoric rock paints from the Lower Pecos using x-ray diffraction, but reported only calcite and gypsum as the minerals composing the rock crusts that cover the paintings. During chemical analysis of several prehistoric paints we identified oxalate as the primary component in the crusts. The aim of the study we report here was to determine the regional occurrence of oxalates in the Lower Pecos and to identify the mineral form.

MATERIALS AND METHODS

Samples of rock crusts were collected from sixteen rock shelters throughout the Lower Pecos region. Samples were taken from the shelter wall directly exposed to sunlight as well as regions remaining shaded throughout the day. All samples were from areas that

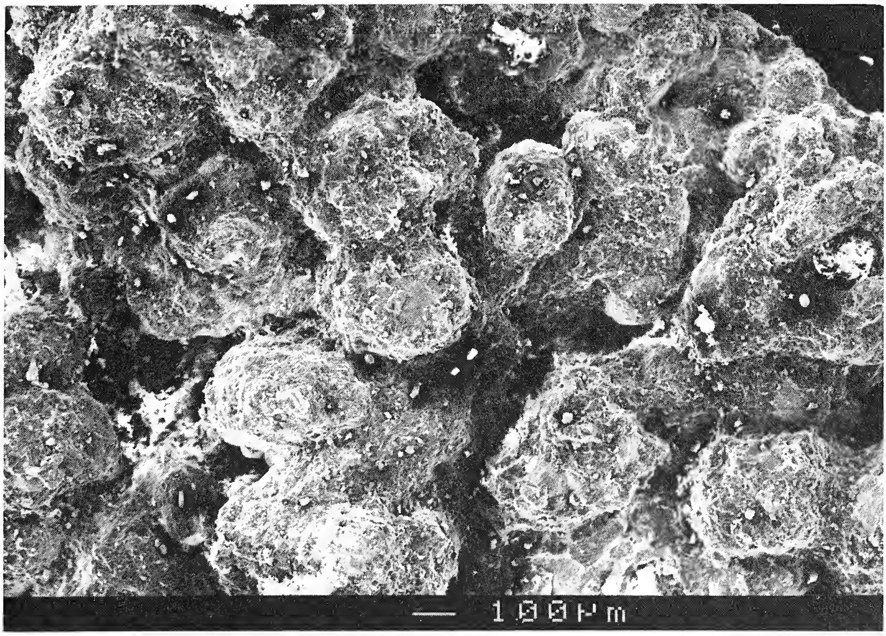

FIGURE 2. SEM photomicrograph of the surface of the oxalate rock crusts collected from Dinner Plate shelter in the Lower Pecos.

are not exposed to rain, rain run-off or ground water seepage. Paint samples were also collected from two sites. The samples were analyzed using optical microscopy, scanning electron microscopy (SEM) with an energy dispersive x-ray analyzer (EDS), Fourier transform infrared spectrometry (FTIR) and powder x-ray diffractometry (XRD).

The SEM/EDS analyses were carried out using a JEOL 6400 SEM equipped with a Noran I-2 Integrated Imaging X-Ray Microanalysis System. Samples were prepared by thin-sectioning after immersing in epoxy or by attaching fragments of the crusts to one centimeter aluminum stubs. The samples were gold sputter coated prior to placing in the SEM.

We used a Nicolet 510P FTIR with a Nicplan infrared microscope to obtain the infrared absorbance spectra. This system allows the infrared beam to be focused through small scrapings of the crust (~0.1 mg) placed in a diamond compression cell. Multiple analyses from each sample were compared for consistency.

The powder XRD was performed using a Rigaku computer automated D/Mx IIIV BX X-ray Powder Diffractometer with a monochromator for selecting the copper K α radiation. Samples were prepared by scraping the crust from the limestone substrate using a stainless steel dental pick and then grinding it in an agate mortar and pestle.

RESULTS

The surface of the crusts have a botryoidal morphology (Fig. 2), with colors ranging from light brown (Munsell designation 5 YR 6/4) to grayish orange (Munsell designation 10 YR 7/4) (Munsell, 1951). When viewed in cross-section under an optical microscope, samples show three distinct layers: the surface rock crust, a white

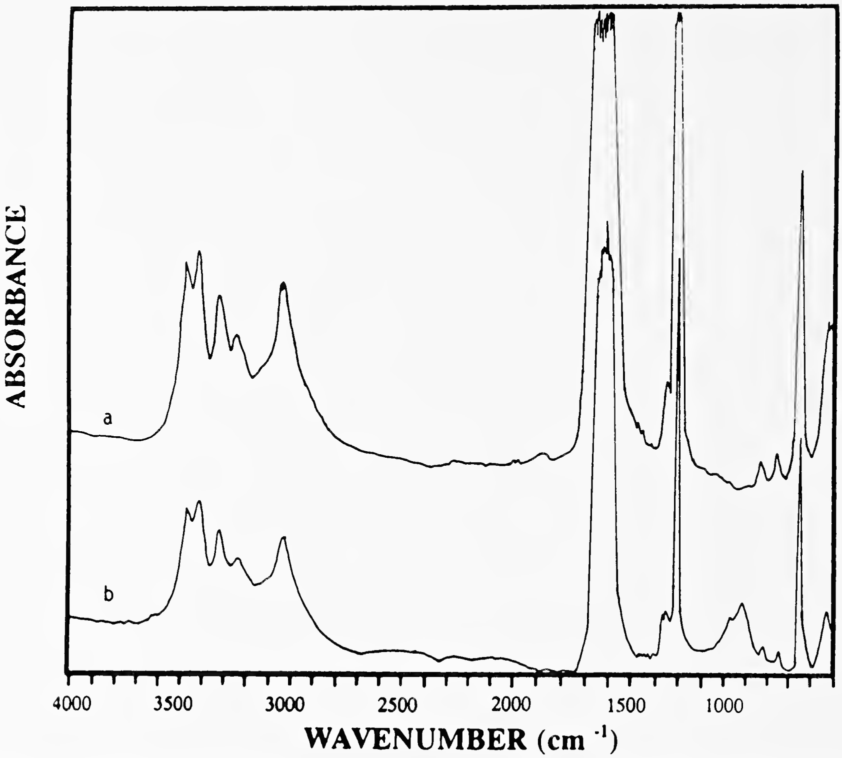

FIGURE 3. FTIR spectra of (a) calcium oxalate standard and (b) natural rock crusts from archaeological site 41VV576 in the Lower Pecos. The only significant difference in the two spectra is a broad peak at 1000 to 1100 wavenumbers indicating either gypsum or quartz in the crusts.

microcrystalline interface and the limestone substrate. Samples containing paint show an additional strata with the paint lying between the crust and interface (Russ et al., 1992b). The thickness of the crust layer averaged 170 μm with a maximum thickness of 850 μm. Only one sample showed stratification of the crust; in that case two layers were observed. This is in contrast to the oxalate-rich crusts in Australia and Italy where multiple layers are common.

Using FTIR, we determined that the crusts from all 16 sites contained oxalate as the primary component. Figure 3 shows an overlay of FTIR spectra of (a) calcium oxalate standard and (b) a sample of crust collected from archaeological site 41VV576. The only significant difference in the two spectra is a broad peak between 1000 to 1100 wavenumbers in the spectrum of the crust. Because both sulphates and silicates absorb in this region, this peak is likely due to gypsum and/or quartz. Figure 4 illustrates the similarities of the FTIR spectra of (a) a sample of red paint from site 41VV576 and (b) a sample

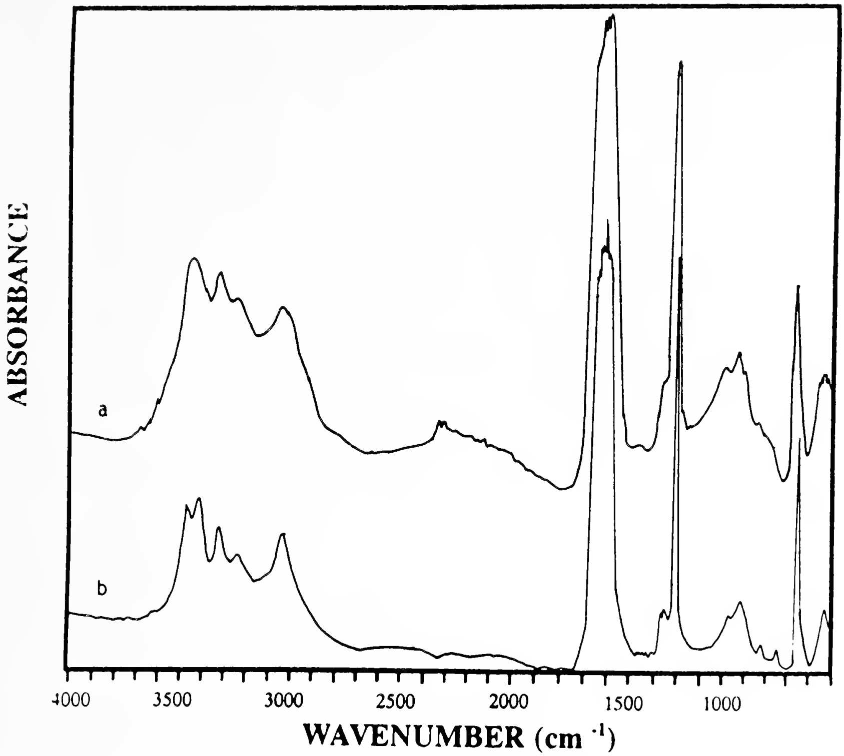

FIGURE 4. FTIR spectra of (a) a scraping from a sample of red paint collected from site 41VV576 and (b) a sample of rock crust from site 41VV576. This shows that the primary component in the paint layer is oxalate.

of crust also from site 41VV576, indicating that the primary component in the paint layer is oxalate.

SEM observation showed that the oxalate is microcrystalline or amorphous, with distinct gypsum ($CaSO_4{\cdot}2H_2O$) crystals dispersed throughout the oxalate phase (Fig. 5). Spherical quartz grains were also seen in several samples. Using EDS we determined that the oxalate crusts contained higher concentrations of the elements aluminum and silicon relative to the substrate, probably from aolian clays. The presence of quartz and clays in the crusts implies that particulate matter accumulated in the crust as it formed.

Results from XRD analyses indicate that the oxalate is in the monohydrate mineral form whewellite. Weddellite, the polyhydrate form of calcium oxalate, was not evident in any of the samples. Gypsum was also identified in the crusts as was quartz and calcite. Figure 6 shows a XRD spectrum of a crust sample from Goat Bone Shelter.

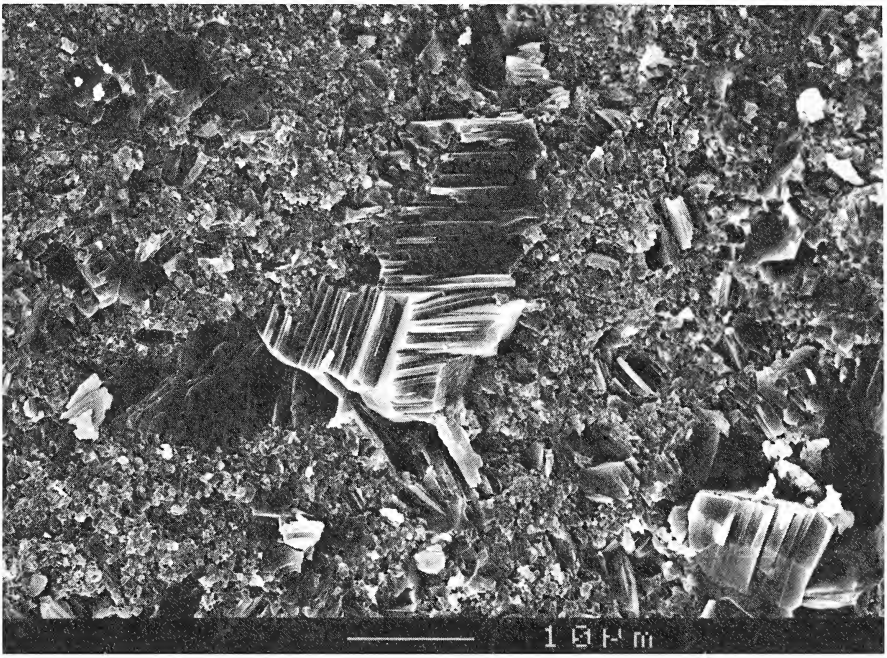

FIGURE 5. SEM photomicrograph of a cross-section of the crust from archaeological site 41VV576 showing distinct, tabular gypsum crystals incorporated in the amorphous or microcrystalline oxalate crust.

DISCUSSION

Whewellite was the primary component of the rock crusts from all 16 sites sampled. This may indicate that the mineral is ubiquitous to the dry rock shelters of the Lower Pecos. The origin of this material is unknown, but we suggest it is the result of metabolic activity of lichen or fungi at the surface of the limestone substrate. The significance of oxalate-rich rock crusts in the Lower Pecos region is that it may provide a means for determining chronologies of the rock paintings without compromising the art and be used as a paleoenvironmental indicator. Furthermore, understanding the processes that form the accretions is imperative for developing viable conservation strategies for the Lower Pecos pictographs.

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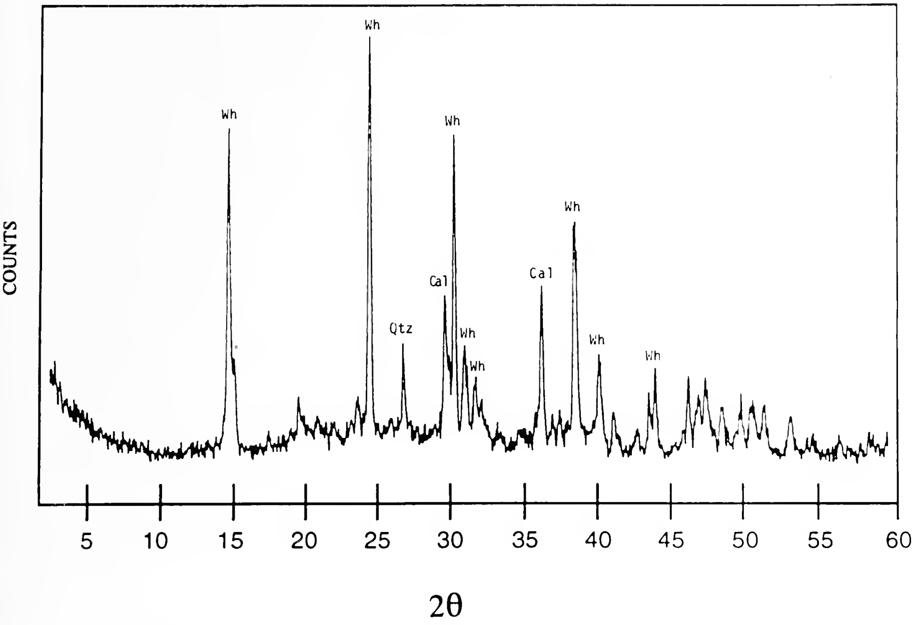

Figure 6. XRD spectrum of rock crust from Goat Bone Shelter. The spectrum shows the presence of whewellite (Wh), calcite (Cal) and quartz (Qtz).

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UTILIZATION OF THE TROPHIC STRUCTURE OF SMALL POND ECOSYSTEMS BY HELMINTHS OF FROGS, *RANA CATESBEIANA* AND *RANA UTRICULARIA*

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Abstract.—One hundred and thirty-three adult *Rana catesbeiana* (bullfrogs), 86 adult *R. utricularia* (southern leopard frogs) and 200 tadpoles of both species were collected from September 1975 through September 1977 in Brazos County, Texas and examined for endohelminths. Adult *R. catesbeiana* were infected with 31 species of helminths, adult *R. utricularia* were infected with 28 helminth species and 17 species of helminths were found in tadpoles. The life cycles of all helminths encountered were verified for south-central Texas through laboratory experiments and/or field observations, and the laboratory and field data collected were used to develop trophic diagrams for the analysis of the role of helminth life cycles in these aquatic ecosystems. *Key words*: trophic structure; ecosystems; helminths; frogs; *Rana*.

Small pond ecosystems are an important resource for many ranches and farms in North America. In south-central Texas these small stock ponds are generally permanent, man-made ecosystems supporting a variety of aquatic and semiaquatic organisms which apparently orginated from the more complex oxbow lake ecosystems. Stock ponds may range in age from those established in pioneer times to those of recent origin. Despite the ubiquity of such ecosystems, there appears to be no synthetic studies on the role of helminth parasites in such ecosystems.

Frogs, *Rana catesbeiana* Shaw, 1802 (bullfrogs) and *Rana utricularia* Collins, 1990 (southern leopard frogs) were universally present in these ponds and were therefore chosen for this study. The purpose was to examine how the helminth parasites of these two species of frogs utilize, through their life cycle strategies, the trophic structures of permanent stock ponds.

Materials and Methods

A total of 133 adult *R. catesbeiana*, 86 adult *R. utricularia* and 200 tadpoles of both species were collected from six permanent stock ponds in Brazos County, Texas from September 1975 through September 1977 and examined for adult and larval helminth parasites. Counts were made of adult and pre-adult helminths, but no counts of larvae were made. Although at least some aspects of the life cycles of most of these helminths had been reported previously (Tables 1 and 2), life cycles were verified for south-central Texas through laboratory experiments and/or field studies. Data collected were used to develop life cycle diagrams (Figs. 1 through 5) and to determine how the life cycle strategies of these helminths utilize the trophic structures of these small stock ponds.

Diagrams which were developed to depict the life cycle strategies of helminths infecting these two species of frogs as definitive hosts (Figs. 1, 2, 3, and 4) are basically composed of three trophic level boxes: 1) C-1, representing the first consumer level (herbivores); 2) C-2, representing the secondary consumer level and 3) C-3, representing the tertiary consumer level (frogs). The area external to the first consumer level box (P) represents those aspects of the primary production level used by the helminths. The diagram depicting the life cycle strategies of helminths utilizing frogs as intermediate hosts (Fig. 5) includes an additional trophic level box (C-4) which represents those consumers which ingest frogs and serve as definitive hosts for frog-borne helminths. Placement of hosts used by the helminths into their respective trophic positions is represented by secondary boxes which are labeled with the category of the host (genus or general group designation) and the helminth life cycle stage established in the host category. Abbreviated designations used for helminth stages are defined in the figure legends. Secondary boxes representing host categories which occupy more than one trophic level are placed overlapping those trophic level boxes in which the particular host category participates. Interactions of helminth life cycles within the different trophic levels of these aquatic ecosystems are displayed as coded lines with directional arrow points which illustrate the pathways used by helminths to move from one host to the next in the pond ecosystems. Coded lines are defined at the top of each figure. A directional arrow point by itself without an adjoining coded line represents helminth egg hatching. Species of helminths utilizing these different pathways are identified by arabic numbers which are defined at the bottom of figures.

RESULTS AND DISCUSSION

Platyhelminths (Figs. 1 through 5) and nematodes (Figs. 4 and 5) were the only helminth groups which utilized these two species of frogs as definitive hosts (Table 1) or intermediate hosts (Table 2). Representative literature citations for known life cycles of helminths encountered in this study are given in Table 1.

Adult *R. catesbeiana* were infected with a total of 31 species of helminths (12 species represented by adult helminths, 19 species represented by larval helminths), while *R. utricularia* were infected with 28 species (9 species represented by adult helminths, 19 species represented by larval helminths). Eight species represented by adult helminths (4 flukes, 1 cestode, 3 nematodes) and all 19 species represented by larval helminths (15 flukes, 4 nematodes) found in *R. utricularia* were shared with adult bullfrogs. Each species of frog was infected by a different species of *Haematoloechus*, while adult *Gorgodera* sp., *Spinitectus* sp. and *Camallanus* sp. were not found in *R. utricularia*. Of the 12 species represented by adults found in mature bullfrogs; six were flukes and five were nematodes. Five species of flukes and three species of nematodes represented by adults were found in *R. utricularia*. *Ophiotaenia gracilis* (mature cestode) was occasionally present in adults of both species of frogs. Prevalences and intensities are given in Table 1. There were no detectable differences in prevalences or intensities between male and female frogs.

TABLE 1. Infection levels of adult helminths from *Rana catesbeiana* and *Rana utricularia* in south-central Texas and representative literature citations for the life cycles previously reported for helminths encountered.

	Rana catesbeiana		*Rana utricularia*		
Helminths	Prevalence	Intensity	Prevalence	Intensity	Citations
Trematodes:					
Allassostomoides chelydrae	9%	2.8 (1-5)	4%	3.0 (1-5)	Beaver, 1929; Byrd & Reiber, 1940; Krull, 1933a
Glypthelmins quieta	33%	6.1 (1-32)	53%	5.7 (1-25)	Leigh, 1946; Rankin, 1944
Gorgodera amplicava	23%	10.2 (1-17)		0 0	Goodchild, 1945, 1948; Krull, 1935a
Haematoloechus breviplexus	29%	5.8 (1-25)		0 0	Schell, 1965; Smith, 1959
Haematoleochus coloradensis		0 0	32%	8.4 (1-45)	Dronen, 1975; Underwood & Dronen, 1977
Halipegus occidualis	8%	2.3 (1-7)	1%	3.0 (1-4)	Krull, 1933b, 1935b; Macy & Demott, 1957; Macy, Cook, & Demott, 1960; Thomas & Johnson, 1934
Megalodiscus intermedius	42%	4.7 (1-18)	51%	4.0 (1-11)	Cary, 1909; Herber, 1938, 1939 Krull & Price, 1932; Smith, 1959, 1967
	6 species		5 species		
Nematodes					
Camallanus pipientis	2%	3.0 (1-11)		0 0	Crites, 1976; Moorthy, 1938; Stromberg & Crites, 1974
Cosmocercoides dukae	39%	76.8 (10-211)	21%	15.9 (1-59)	Anderson, 1960; Baker, 1978
Gyrinicola batrachiensis[1]	55%	9.5 (4-26)	70%	11.0 (1-30)	Adamson, 1981
Rhabdias ranae	8%	6.3 (1-21)	9%	8.0 (2-21)	Baker, 1979a, 1979b
Spinitectus carolini	2%	2.7 (1-5)		0 0	Gustafson, 1939; Jilek & Crites, 1982a, 1982b
	6 species		5 species		
Cestodes:					
Ophiotaenia gracilis	3%	1.6 (1-4)	4%	2.0 (1-3)	Herde, 1938; Magath, 1928; Thomas, 1934, 1941
	1 species		1 species		

[1] Found only in tadpoles.

Table 2. Prevalence of larval helminths from adults and tadpoles of *Rana catesbeiana* and *Rana utricularia*, including a list of their definitive hosts in south-central Texas.

Helminths	*Rana catesbeiana* Adult	*Rana catesbeiana* Tadpole	*Rana utricularia* Adult	*Rana utricularia* Tadpole	Definitive Hosts
Trematode metacercariae:					
Cephalogonimidae					
Cephalogonimus vesicaudus	16%	66%	22%	72%	*Trionyx spiniferus*
Clinostomatidae					
Clinostomum sp.	14%	0%	21%	0%	*Bulbulcus ibis*, *Casmerodius albus* (probably other piscivorous birds)
Diplostomatidae					
Neascus sp.	2%	1%	1%	5%	Piscivorous birds (species not known)
Macroderoididae					
Glypthelmins quieta	0%	0%	26%	0%	*Rana catesbeiana*, *Rana utricularia*
Macroderoides typicus	37%	40%	12%	62%	*Lepisosteus oculatus*
Paramaroderoides echinus	23%	47%	13%	36%	*Lepisosteus oculatus*
Ochetosomatidae	18%	37%	9%	72%	
Dasymetra conferta					*Nerodia erythrogaster*, *Nerodia fasciata*, *Nerodia rhombifera*
Ochetosoma aniarum					*Heterodon platyrhinos*, *Lampropeltis getula*, *Nerodia erythrogaster*, *Nerodia fasciata*, *Nerodia rhombifera*
Ochetosoma ellipticum					*Agkistrodon contortrix*, *Agkistrodon piscivorous*, *Heterodon platyrhinos*, *Masticophis flagellum*
Pneumatophilus variabilis					*Nerodia erythrogaster*, *Nerodia fasciata*, *Nerodia rhombifera*
Paramphistomatidae	8%	3%	5%	2%	
Allassostomoides chelydrae					*Rana catesbeiana*, *Rana utricularia*, *Chelydra serpentina*, *Trachemys scripta*
Megalodiscus intermedius					*Rana catesbeiana*, *Rana utricularia*

TABLE 2. Continued

Telorchidae	15%	8%	10%	80%	
Auridistomum chelydrae					*Chelydra serpentina*
Protenes angustus					*Trachemys scripta*
Telorchis clavi					*Chelydra serpentina*
Telorchis corti					*Pseudemys concinna, Sternotherus odoratus*
Nematode Larvae:					
Dioctophymidae					
Eustrongylides sp.	24%	0%	11%	0%	*Piscivorous birds (species not known)*
Hetrocheilidae					
Contracaecum sp.	5%	0%	2%	0%	*Piscivorous birds (species not known)*
Spiruridae	12%	0%	29%	0%	
Spiroxys contortus					*Trachemys scripta, Pseudemys concinna*
Spiroxys amydae					*Trionyx spiniferus*
Cestode Pleroceroids:					
Proteocephalidae	0%	27%	0%	7%	
Ophiotaenia perspicua					*Nerodia erythrogaster, Nerodia fasciata, Nerodia rhombifera*
Ophiotaenia testudo					*Trionyx spiniferus*

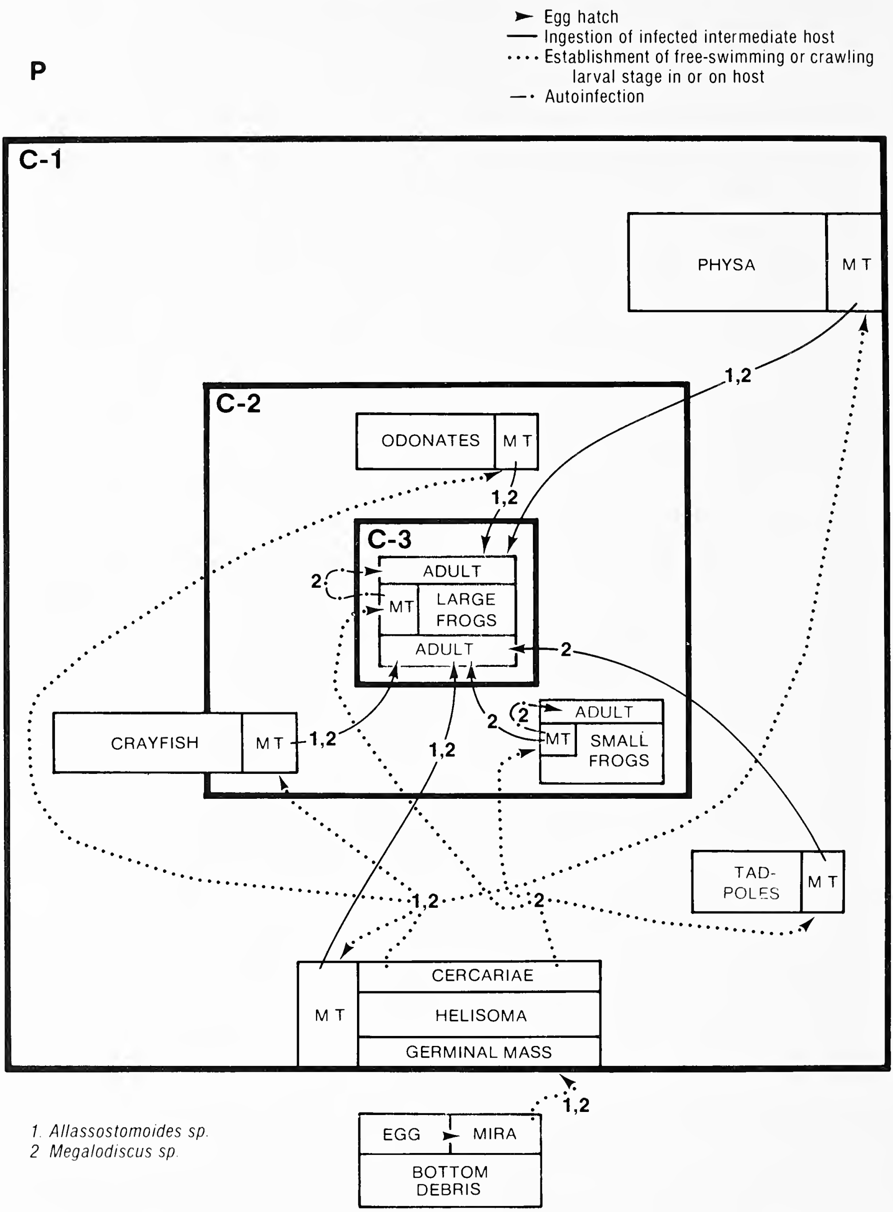


FIGURE 1. Life cycle strategies of *Allassostomoides chelydrae* and *Megalodiscus intermedius* showing the general trophic positions in the aquatic ecosystem of their respective hosts and indicating the parasite life cycle stages present in each host category. Digenea stages shown are: Adults (ADULT), cercariae (CERCARIAE), eggs (EGG), stages of polyembryony in molluscan hosts (GERMINAL MASS), miracidia (MIRA), metacercariae (MT). Trophic levels indicated are: herbivores (C-1), secondary consumers (C-2), tertiary consumers (C-3), producers (P).

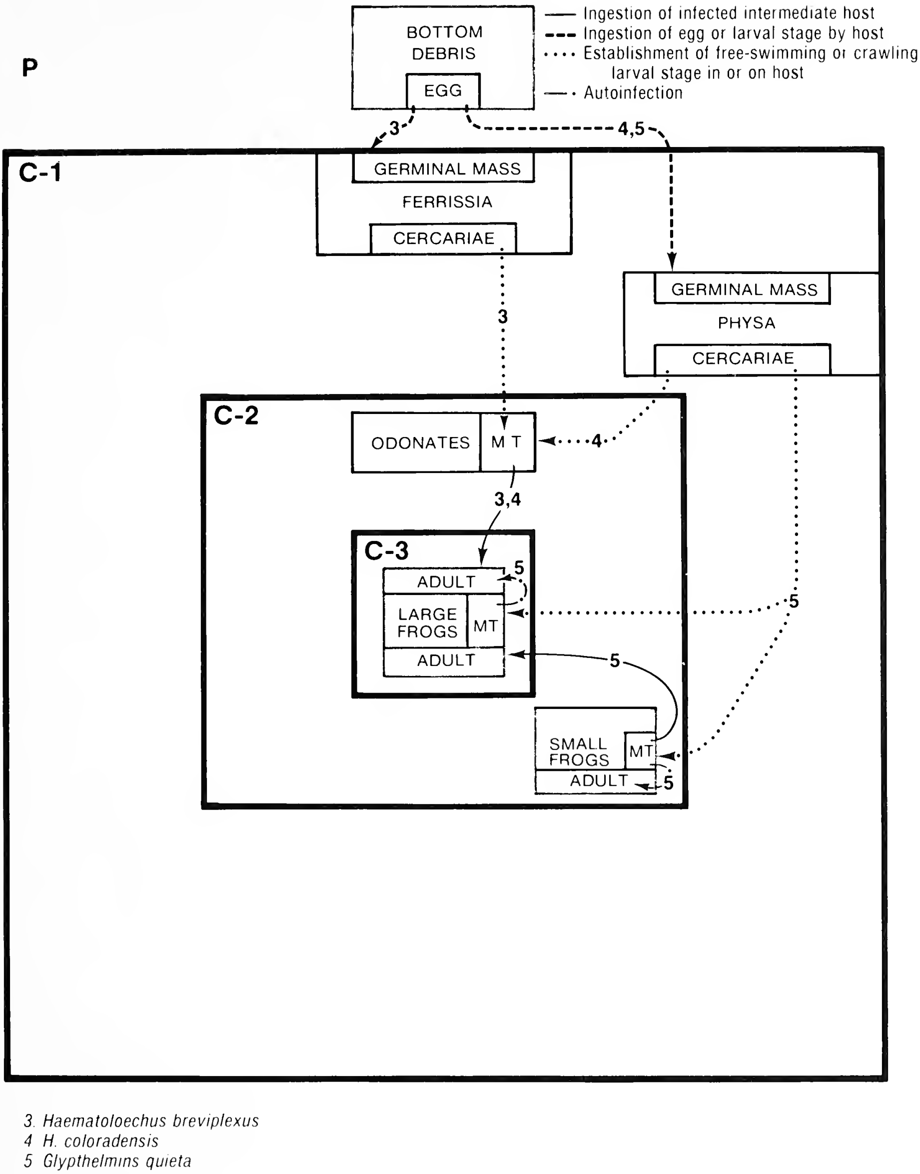


FIGURE 2. Life cycle strategies of *Haematoloechus breviplexus, H. coloradensis* and *Glypthelmins quieta* showing the general trophic positions in the aquatic ecosystem of their respective hosts and indicating the parasite life cycle stages present in each host category. Digenea stages shown are: Adults (ADULT), cercariae (CERCARIAE), eggs (EGG), stages of polyembryony in molluscan hosts (GERMINAL MASS), miracidia (MIRA), metacercariae (MT). Trophic levels indicated are: herbivores (C-1), secondary consumers (C-2), tertiary consumers (C-3), producers (P).

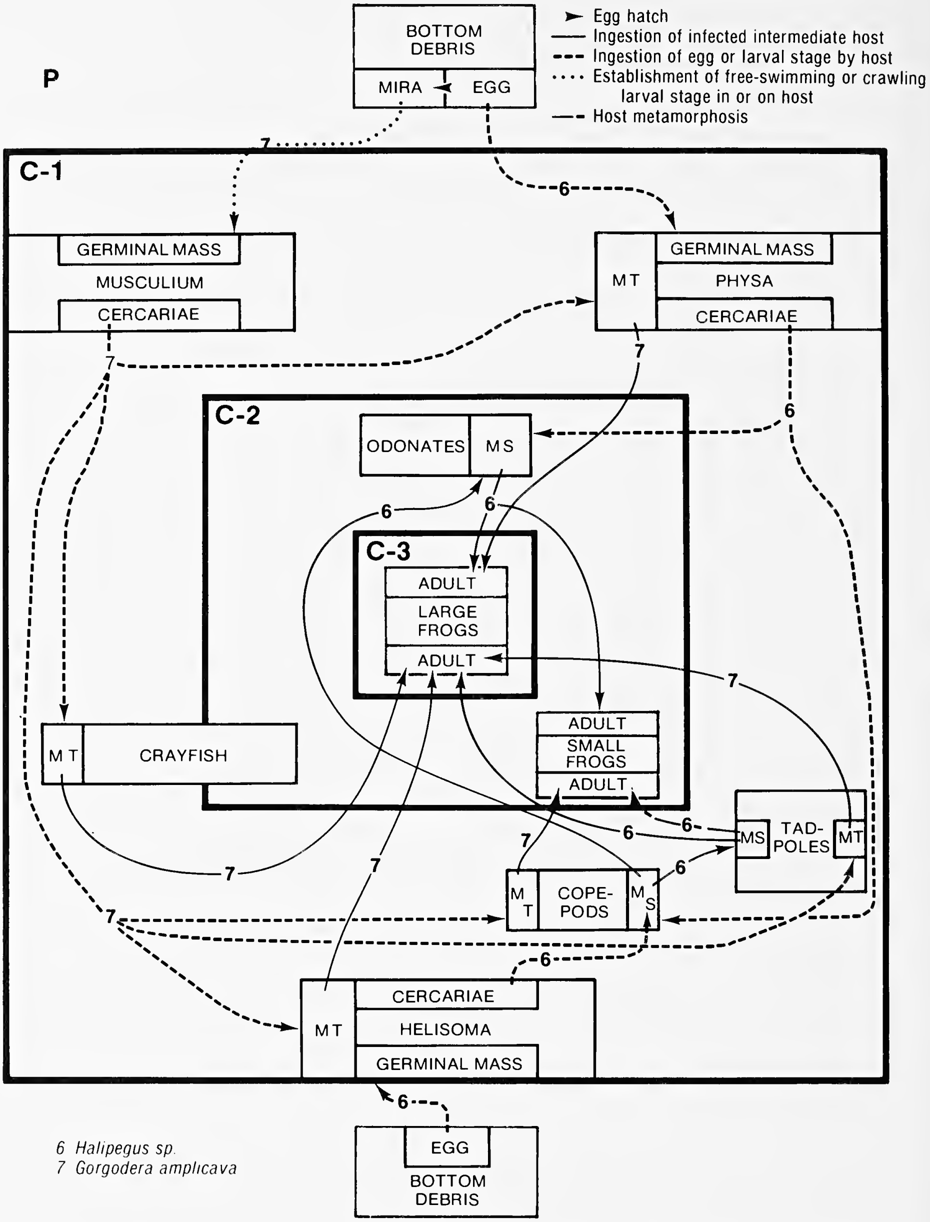


FIGURE 3. Life cycle strategies of *Halipegus occidualis* and *Gorgodera amplicava* showing the general trophic positions in the aquatic ecosystem of their respective hosts and indicating the parasite life cycle stages present in each host category. Digenea stages shown are: Adults (ADULT), cercariae (CERCARIAE), eggs (EGG), stages of polyembryony in molluscan hosts (GERMINAL MASS), miracidia (MIRA), metacercariae (MT). Trophic levels indicated are: herbivores (C-1), secondary consumers (C-2), tertiary consumers (C-3), producers (P).

Tadpoles had 14 species of helminths represented by larvae which were shared with adult frogs but larvae of *Glypthelmins* sp., *Clinostomum* sp., *Contracaecum* sp., *Eustrongylides* sp. and two species of *Spiroxys* were not found in tadpoles. Two species of *Ophiotaenia* (one maturing in turtles, one in water snakes) and the metacercaria of *Cephalogonimus vesicaudus* (maturing in turtles) were found in tadpoles but not in adult frogs. *Gyrinicola batrachiensis* (nematode) was the only adult helminth in tadpoles and was not found in either species of adult frogs. Of the 19 larval helminths found in adult frogs; two mature in fish, two in amphibians, 10 in reptiles (6 in turtles, 4 in snakes), 4 in piscivorous birds and one in both reptiles (turtles) and amphibians (frogs) (Table 2).

Life Cycle Strategies

Platyhelminths, primarily represented by Digenea (flukes), were the most prevalent helminths found. The neascus encountered was *Posthodiplostomum* sp. Molluscan first intermediate hosts for flukes became infected either by ingestion of eggs from bottom debris, as in *Cephalogonimus* sp., *Glypthelmins* sp., *Haematoloechus* spp., *Halipegus* sp., macroderoidids, ochetosomatids and telorchids; or by direct penetration of free-swimming miracidia hatched from eggs deposited in the bottom debris, as in *Allassostomoides* sp., *Clinostomum* sp., *Gorgodera* sp., *Megalodiscus* sp. and *Neascus* sp. (*Posthodiplostomum* sp.). In species of flukes where ingestion of eggs was required, eggs hatched in the intestines of molluscan hosts and the released miracidia penetrated the intestinal epithelium. In either method of snail infection, miracidia became the first germinal masses which initiated polyembryony in this host category. The end product of this reproductive process in molluscan hosts was free-swimming larvae, the cercariae, which left snail hosts to infect the next hosts in their respective life cycles, or to encyst upon appropriate substrates. Life cycle strategies of flukes using these two species of frogs as definitive hosts (Figs. 1 through 3) or intermediate hosts (Fig. 5) can be divided into three general types: 1) cercariae formed metacercariae on a substrate external to a host (Fig. 1; *Allassostomoides* sp., *Megalodiscus* sp.); 2) cercariae penetrated into a second intermediate host forming metacercariae (Figs. 2 and 5; *Cephalogonimus* sp., *Clinostomum* sp., *Glypthelmins* sp., *Haematoloechus* spp., macroderoidids, ochetosomatids, *Posthodiplostomum* sp., telorchids) and 3) cercariae were directly ingested by a second intermediate host, forming metacercariae or mesocercariae (unencysted metacercariae) within the host (Fig. 3; *Gorgodera* sp., *Halipegus* sp.) In the first strategy, definitive hosts became infected by ingesting the substrate on which metacercariae had become established (vegetation, exoskeletons of

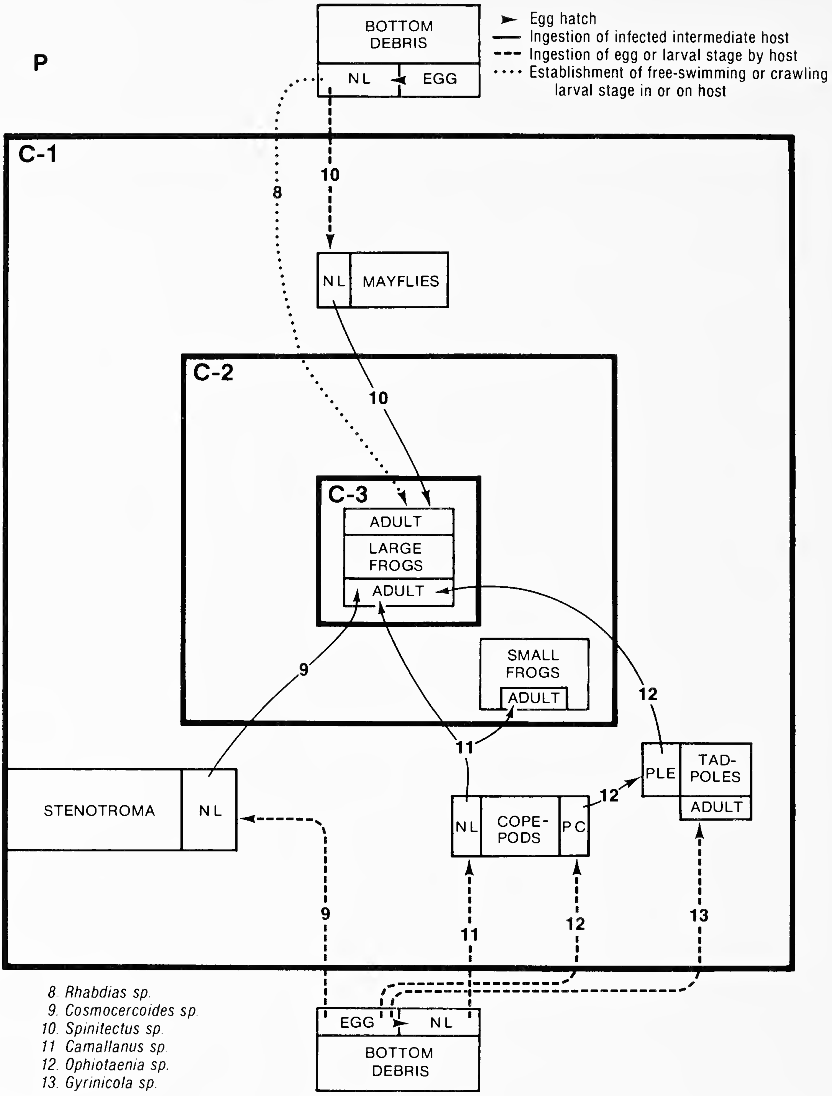
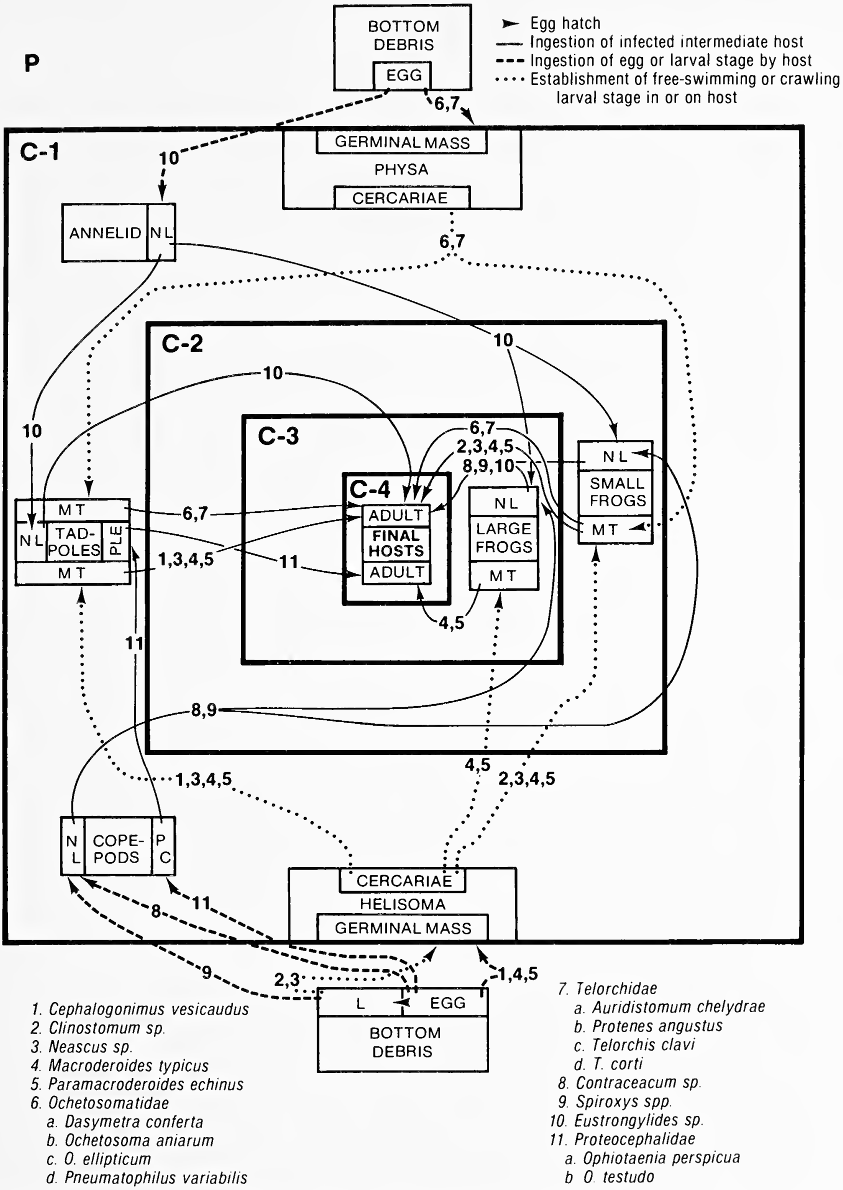


FIGURE 4. Life cycle strategies of *Rhabdias ranae, Cosmocercoides dukae, Spinitectus carolini, Camallanus pipientis, Ophiotaenia gracilis* and *Gyrinicola batrachiensis* showing the general trophic positions in the aquatic ecosystem of their respective hosts and indicating the parasite life cycle stages present in each host category. Cestode and nematode stages shown are: Adults (ADULT), eggs (EGG), nematode larvae (NL), procercoid larvae (PC), plerocercoid larvae (PLE). Trophic levels indicated are: herbivores (C-1), secondary consumers (C-2), tertiary consumers (C-3), producers (P).



1. *Cephalogonimus vesicaudus*
2. *Clinostomum sp.*
3. *Neascus sp.*
4. *Macroderoides typicus*
5. *Paramacroderoides echinus*
6. *Ochetosomatidae*
   - a. *Dasymetra conferta*
   - b. *Ochetosoma aniarum*
   - c. *O. ellipticum*
   - d. *Pneumatophilus variabilis*
7. *Telorchidae*
   - a. *Auridistomum chelydrae*
   - b. *Protenes angustus*
   - c. *Telorchis clavi*
   - d. *T. corti*
8. *Contraceacum sp.*
9. *Spiroxys spp.*
10. *Eustrongylides sp.*
11. *Proteocephalidae*
   - a. *Ophiotaenia perspicua*
   - b *O. testudo*

FIGURE 5. Life cycle strategies of helminth parasites which utilize *Rana catesbeiana* and *Rana utricularia* as intermediate hosts showing the general trophic positions in the aquatic ecosystems of their respective hosts and indicating the parasite life cycle stages present in each host category. Cestode, nematode and trematode stages shown are: Adults (ADULT), cercariae (CERCARIAE), eggs (EGG), stages of polyembryony in molluscan hosts (GERMINAL MASS), digenean and nematode larvae (L), metacercariae (MT), nematode larvae (NL), procercoid larvae (PC), plerocercoid larvae (PLE). Trophic levels indicated are: herbivores (C-1), secondary consumers (C-2), tertiary consumers (C-3), quaternary consumers (C-4), producers (P).

invertebrates, skin of vertebrates, etc.). In the latter two strategies, definitive hosts were generally infected by eating infected second intermediate hosts, but some infections occurred by autoinfection (digestion of their own infected skin), as seen in *Glypthelmins* sp.

Proteocephalid tapeworms generally used two intermediate host levels (Figs. 4 and 5): 1) copepods were infected by ingestion of eggs deposited in the bottom debris producing procercoid larvae (first larval stage) in the hemocoel of these hosts and 2) tadpoles ingested these infected copepods and plerocercoid larvae (second larval stage) developed in the body cavity and associated tissues of these hosts. Definitive hosts became infected by eating infected second intermediate hosts (tadpoles).

Nematodes were the second most prevalent group of helminths (Figs. 4 and 5), being represented by three basic life cycle strategies: 1) the definitive hosts were directly infected by ingestion of eggs or infective larvae, as in *Rhabdias* sp. and *Gyrinicola* sp. (Fig. 4); 2) a first intermediate host only was utilized, as in *Spinitectus* sp., *Camallanus* sp. and *Cosmocercoides* sp. (Figs. 4 and 5) and 3) eggs or larvae were ingested by first intermediate hosts and these hosts were in turn ingested by second intermediate hosts, as in *Contracaecum* sp., *Spiroxys* spp. and *Eustrongylides* sp. (Fig. 5). In the first strategy parasites were able to bypass intermediate trophic levels and adults developed directly in the definitive host without passing through intermediate hosts, while in the latter two strategies the ingestion of intermediate hosts was required.

Trophic Diagrams

The diagrammatic representations (Figs. 1 through 5) show how the life cycle stages of the helminths of leopard frogs, *R. utricularia*, and bullfrogs, *R. catesbeiana*, utilize the trophic structures of small pond ecosystems. Generally, the youngest larval stages in these life cycles use the lower trophic level represented by the largest of the concentric boxes (C-1), while the more advanced larval stages are found in the intermediate trophic levels (C-2, C-3), ultimately becoming adults in the highest trophic levels (C-3, C-4). Advancement from lower trophic levels to higher trophic levels is generally achieved through using the food chains of the trophic structure. To insure success in these hazardous transfers, helminths typically display a high reproductive potential to offset a low infection efficiency at each stage of their life cycles. Dronen (1978) provided estimates of the efficiencies of *Haematoloechus coloradensis* (one of the species encountered in this study) over a two year period and found low efficiencies at all levels of the life cycle: eggs producing miracidia which successfully infected snails (0.02%); cercariae realized from total eggs produced (3.9%);

metacercariae actually produced from available cercariae (0.09%) and immature flukes realized from metacercariae available (0.5%). Relatively little is known concerning the amount of energy required to support the high reproductive potential of helminths. With the current resurgence of interest in food chain analyses (Yodzis, 1989), such studies should consider both the amount of energy consumed by parasites and the rates of parasite transmission through food chains.

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GENERAL NOTES

GROWTH MODELS OF LOBLOLLY AND SHORTLEAF PINE RED-COCKADED WOODPECKER NESTING TREES

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The red-cockaded woodpecker (*Picoides borealis* Viellot) was originally found throughout the pine forest region of the southeastern United States (USFWS, 1985) but is now on the endangered species list (USFWS, 1993). Red-cockaded woodpeckers excavate nesting and roosting cavities exclusively in living pine trees. Because of the fragmented nature of stands containing suitable cavity trees in the southern United States, and particularly in the loblolly (*Pinus taeda* L.) and shortleaf (*P. echinata* Mill.) pine stands in the national forests in Texas, intensive management is needed. Information on cavity tree growth parameters is one of many aspects of red-cockaded woodpecker ecology that needs to be explored to devise adequate management plans. The objective of this note is to develop height growth models based on age of loblolly and shortleaf pine red-cockaded woodpecker nesting trees.

Following a series of tornadoes, wind thrown red-cockaded woodpecker nesting trees from the Angelina and Davy Crockett National Forests in Texas were subjected to stem analysis. The trees were broken off in a random fashion by the tornadoes. They were then pieced back together to allow the fallen loblolly and shortleaf pine trees to be cut at the root collar and sectioned at 61 centimeter intervals. A section was removed from the top of each log. These sections were then taken to the laboratory where they were sanded and growth rings

Table 1. Regression coefficients and asymptotic standard errors for the Chapman -Richards function parameters.

Species	Regression Coefficient	Asymptotic Std. Error	r^2
both species			
b_1	113.557	5.818	.969
b_2	0.015	0.002	
b_3	-0.107	0.054	
loblolly pine			
b_1	106.767	9.085	.962
b_2	0.015	0.004	
b_3	-0.147	0.093	
shortleaf pine			
b_1	140.940	8.496	.976
b_2	0.010	0.001	
b_3	-0.206	0.039	

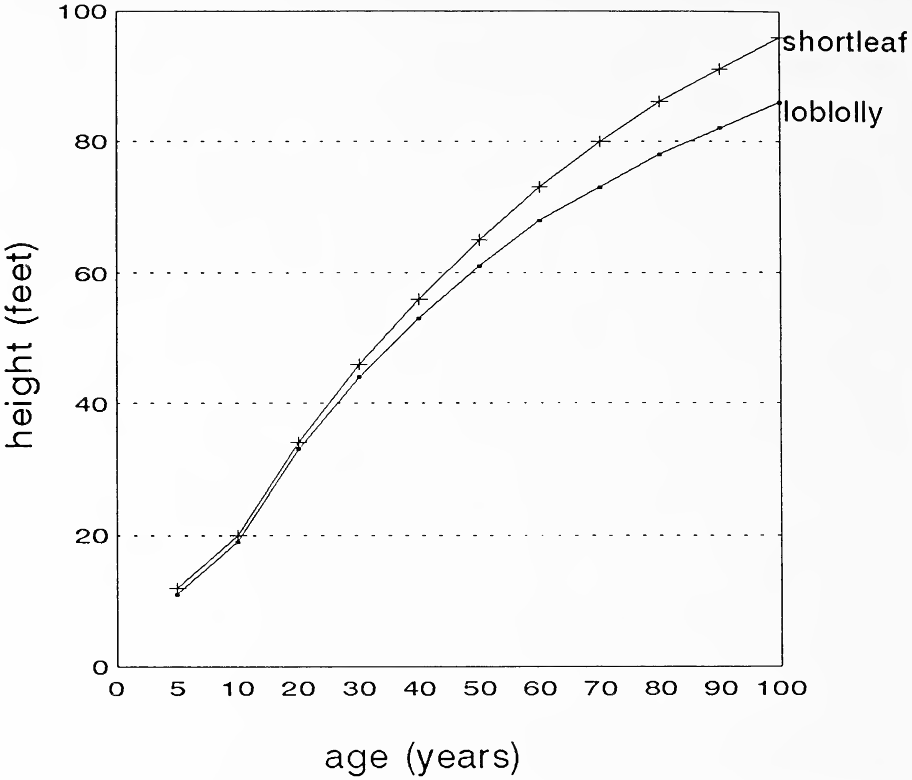

Figure 1. Relationship of height (feet) versus age (years) for loblolly pine and shortleaf pine.

counted and recorded. True heights within the bolts of wood were estimated using the technique recommended by Carmean (1972).

Sampled trees ranged in age from 77 years to 123 years with an average of 99 years and a standard deviation of 13.3 years. These trees ranged in height from 23.2 to 32.9 meters with a mean of 27.9 meters and a standard deviation of 3.0 meters. The stem analysis trees yielded 462 height-age pairs, of which, 179 were loblolly pine and 283 were shortleaf pine. Three trees were not used because heart rot rendered them useless. Because these trees were from nesting colonies of an endangered species, it was impossible to extract more data (barring another natural calamity).

A height growth model using the Chapman-Richards (1959, 1961) function:

$$Y = b_1 [1.0\text{-EXP}(-b_2 * \text{Age})]^{(1/1-b_3)}$$

where: Y = Tree height (feet); b_i = parameters to be determined [1]

produced an excellent fit ($r^2 = .969$) when applied to the entire data set. A plot of the residuals showed no adverse biases or trends. The same method was applied to the data by species. Regression coefficients, standard errors, and r^2's for all regressions are shown in Table 1.

After inserting the regression coefficients from Table 1 into the Chapman-Richards function, the following equations resulted:

loblolly pine Height = $106.767 [1.0\text{-EXP}(-0.015 * \text{Age})]^{0.872}$ [2]

shortleaf pine Height = $140.940 [1.0\text{-EXP}(-0.010 * \text{Age})]^{0.829}$ [3]

When plotted, these models display curves (Fig. 1) that follow the growth patterns of trees selected by red-cockaded woodpeckers for nesting. Because of the limited sample size, these models do not represent the universe of all loblolly and shortleaf pine cavity trees, but may be a useful reference for further studies.

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FIRST RECORD OF A NATIVE AMERICAN ELK (*CERVUS ELAPHUS*) FROM TEXAS

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Reported sightings of American elk in the 1800's (Bailey, 1905) indicate that this species inhabited certain regions of Texas, although there are no modern voucher specimens (Stangl et al., 1994) or fossil records (Dalquest and Schultz, 1992) to substantiate these claims. The first physical evidence of native *C. elaphus* from Texas is reported herein.

On 17 April 1993, the distal portion of a tibia (Fig. 1), identifiable as an adult *C. elaphus*, was found in a cutbank of a small tributary of Pony Creek, 11 km north-northeast of Seymour, Baylor County, Texas. The cutbank exposes fine clay sediments and three layers of gravel, each layer being about three inches thick. The tibia was at the base of the lowest gravel layer, two feet beneath the level of the surrounding flood plain.

The distal end of the tibia of *C. elaphus* differs from that of *Bison bison* in the following characters: longitudinal ridges (muscular lines) found on the posterior side of *B. bison* are absent in *C. elaphus*; a tuberosity present on the anterior side is positioned further from the distal end than in *B. bison* (Fig. 1A); the shaft in *C. elaphus* is more slender than that of *B. bison*.

A radiocarbon (mass spectrometer) date of 295 +/− 50 YBP (Beta Analytic, Inc. #62592) was obtained from a fragment of the bone. It is uncertain whether this specimen represents a member of a substantial population of elk that once lived in the area or only a wandering individual. There are many records of elk from Oklahoma, and a native population existed in the Wichita Mountains until 1881 (Stangl et al., 1992). It is quite possible, taking the wide ranging and migratory habits of this animal into account, that individuals occasionally wandered south from these areas. This specimen is housed in the Midwestern State University Collection of Fossil Vertebrates (MWSU 12946).

I wish to thank W. W. Dalquest and F. B. Stangl, Jr. for their help in preparing this manuscript and Jesse Rogers, Academic Vice President of Midwestern State University, for funding the age determination of the bone.

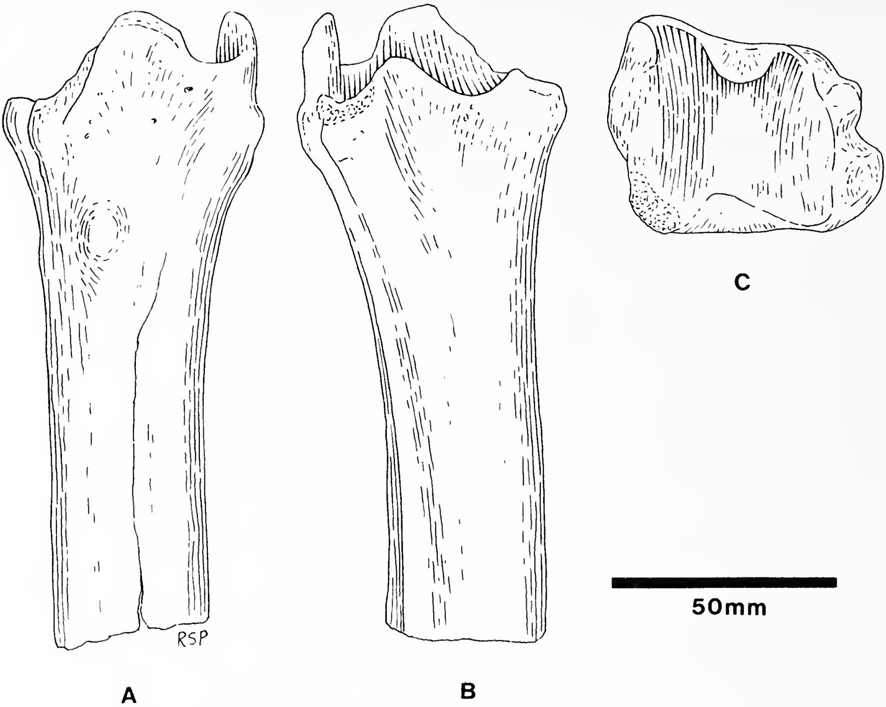

FIGURE 1. Anterior (A), posterior (B), and basal (C) view of the distal portion of a tibia from *Cervus elaphus*, MWSU 12946.

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OCCURRENCE OF THE RED ALGA *LOMENTARIA BAILEYANA* AND ASSOCIATED ROCKY INTERTIDAL MACROALGAE FROM THE MOUTH OF THE COLORADO RIVER, TEXAS

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The algal flora of the rocky intertidal substrates (jetties and groins) of the Gulf of Mexico in the Galveston and Port Aransas, Texas areas is relatively well-documented (Edwards, 1970;

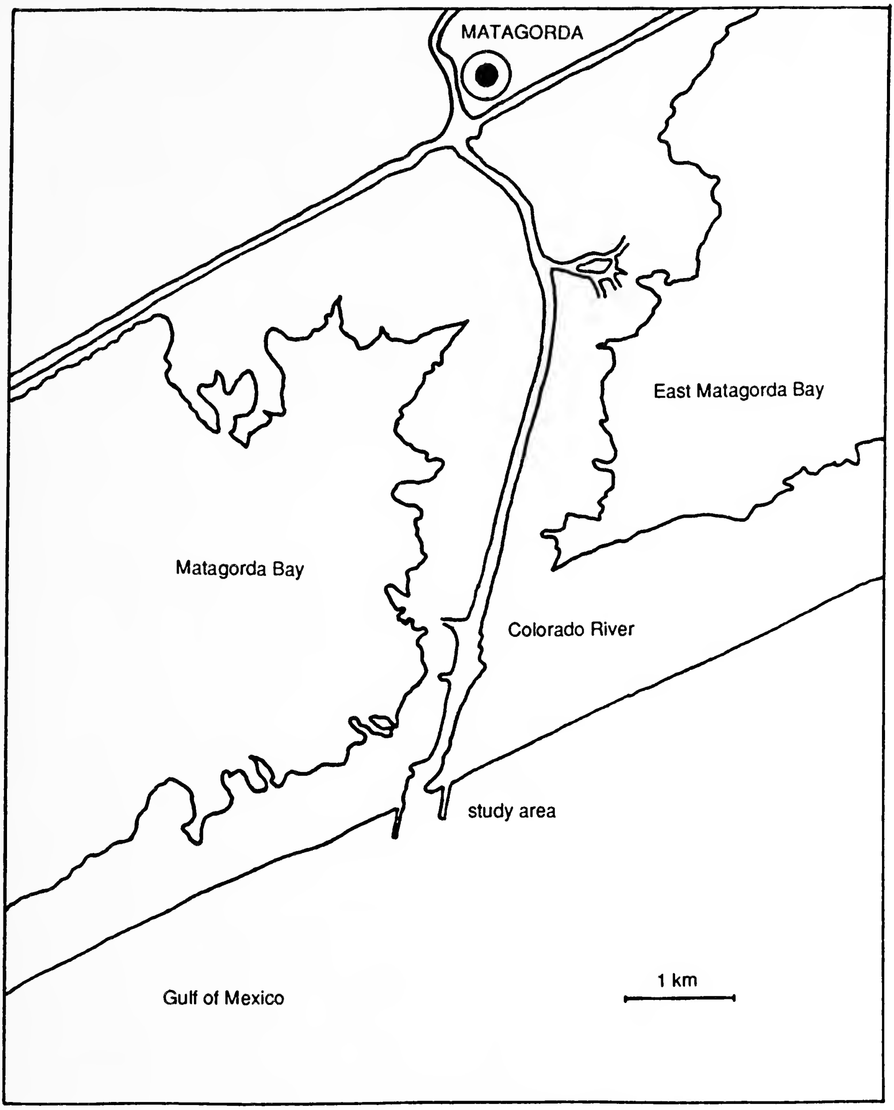

FIGURE 1. Map of the mouth of the Colorado River showing the easternmost jetty (study area) from which benthic macroalgal samples were collected.

Edwards and Kapraun, 1973; Lowe and Cox, 1978; Kapraun, 1980; Medlin, 1984; Wardle, 1992). Information on the algal flora of the Texas coast between these points is lacking. An unpublished report by Keatts (1969) on the algal flora of the Freeport jetty was cited and summarized in Lowe and Cox (1978), but was presently unavailable.

Intertidal algae were collected from the easternmost jetty projecting into the Gulf of Mexico adjacent to the mouth of the Colorado River at Matagorda, Texas (Fig. 1) on 28 January, 21 February and 25 March 1993. Specimens were hand collected from each of the three vertical intertidal zones described in Edwards (1970). Qualitative samples from each zone were taken by hand scraping approximately 100 mm^2 patches of algal growth from areas

TABLE 1. Occurrence of marine macroalgal species on the easternmost jetty adjacent to the mouth of the Colorado River near Matagorda, Texas, 1993.

Species	Date		
	28 January	21 February	25 March
Division Chlorophyta			
Chaetomorpha linum (Müller) Kützing	+	+	+
Cladophora dalmatica Kützing	+	−	−
Enteromorpha clathrata (Roth) Greville	+	+	−
E. lingulata J. Agardh	+	+	+
E. prolifera (Müller) J. Agardh	+	+	+
Division Rhodophyta			
Bangia atropurpurea *(Roth) C. Agardh	+	+	+
Bryocladia cuspidata (J. Agardh) De Toni	+	+	+
Lomentaria baileyana (Harvey) Farlow	+	+	+

*This species was reported by Edwards (1970) and by Lowe and Cox (1978) as *B. fuscopurpurea* (Dillwyn) Lyngbye

where apparent differences in coloration and texture indicated the possibility of the existence of different algal species. Quantification was not attempted. The jetty is composed of granite blocks and projects southward approximately 335 meters into the Gulf of Mexico. It varies in width from 7.5 to 9 meters. Its intertidal zone supports a continuous community of macroalgae, both on the eastern (Gulf) and on the western (river) sides. Salinity on the river side of the jetty ranged from 20 to 22.5 ppt, and that on the Gulf side was 25 ppt for each sampling occasion. No freezing temperatures were recorded during the study.

The algal species collected during each month of the study are summarized in Table 1. Nomenclature follows that of Wynne (1986).

The higher part of the intertidal zone was dominated by turfs of *Bangia atropurpurea* on both the Gulf and river sides of the jetty. In the middle of the interidal zone, *Enteromorpha lingulata* was dominant on the river side and *Lomentaria baileyana* was dominant on the Gulf side. The lower intertidal zone was sparsely populated by *Cladophora dalmatica* and *Enteromorpha clathrata* on the river side and heavily populated by *L. baileyana* on the Gulf side, with occasional specimens of *Bryocladia cuspidata*. Abundant specimens of *Chaetomorpha linum*, and infrequent specimens of *Enteromorpha prolifera* and *Bangia atropurpurea* were found mainly in tidepools in the supratidal zone and in the upper intertidal zones on both sides of the jetty.

Most notable during the study was the occurrence of a substantial population of *Lomentaria baileyana*. This species has not been reported from the Galveston or Freeport jetties (Keatts, unpublished report cited in Lowe and Cox, 1978). Although it was reported by Edwards (1970) from the southwest jetty at Port Aransas, it was listed as a rare summer species. Bird (1978) stated that *L. baileyana* is considered to be a warm-water species, but noted that Eldelstein et al. (1967) have reported it as far northward as southern Canada.

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ATYPICAL NESTING SITES OF THE CACTUS WREN

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The cactus wren (*Campylorhynchus brunneicapillus*) nests in a variety of spinescent trees and shrubs, e.g., cholla cactus (*Opuntia* sp.), columnar cacti (*Cereus* sp.), acacia (*Acacia* sp.), and mesquite (*Prosopis* sp.), and rarely in other native, non-spinescent vegetation, e.g., mistletoe (*Phoradendron* sp.) and hackberry (*Celtis reticulata*; Bent, 1948; Anderson and Anderson, 1973; Harrison, 1979). Cholla cacti seem to be preferred nest sites throughout much of the range of the species (Selander, 1964; McGee, 1985; Ehrlich et al., 1988; Rea and Weaver, 1990; Farley, personal observation). Bent (1948) suggested that cactus wrens are strongly dependent on native vegetation and are probably absent where native plant species have been eliminated. During more than 30 years of observations of cactus wren, Anderson and Anderson (1973) noted only occasional use of "introduced plants such as palm and olive".

We observed cactus wrens nesting in a variety of non-native and non-spinescent vegetation in Arizona and New Mexico in recent years. On 10 March 1993, 8 kilometers south of Deming, Luna County, New Mexico, we saw six nests in salt cedar (*Tamarix chinensis*), 2.6-5.0 meters tall (Fig. 1). The nests were of typical construction and were 2.0-3.1 meters above ground; the nest opening orientation seemed to be random. On the same day at this site, we also saw a singing male in a Siberian elm (*Ulmus pumila*) near a nest. This nest was also of typical construction and 4.0 meters above ground in the 8.0 meter tall tree. Salt cedar and Siberian elm are common naturalized exotics throughout the desert Southwest and are in small numbers at this locality in an otherwise typical Chihuahuan Desert scrub habitat.

Observations in native, non-spinescent vegetation include the following: an active nest, 3.0 meters above ground, in a 5.0 meter tall desert willow (*Chilopsis linearis*) in Portal, Cochise County, Arizona, on 16 April 1991; a nest, 2.7 meters above ground, in a 3.2 meter tall Mormon tea (*Ephedra trifurca*) in the Florida Mountains, south of Deming, Luna County, New Mexico, on 10 March 1993; three nests (one of which contained a female incubating two eggs), 2.1-3.6 meters above ground, in the inflorescence of 2.6-4.1 meter tall soaptree yuccas (*Yucca elata*) on the San Andres National Wildlife Refuge, Doña Ana County, New Mexico, on 28 July 1993. Two of the yuccas at the refuge also supported abandoned nests

Figure 1. Three cactus wren nests in a 4.0 meter tall salt cedar (*Tamarix chinensis*). The uppermost nest appeared to be in use when photographed on 10 March 1993.

within the leaf cluster of the plant, the more typical location of a cactus wren nest in this plant.

We were unable to determine if most of these nests were used solely as nighttime roosting sites or in attempted reproduction. However, our observations indicate that cactus wrens use non-native trees in habitat that is otherwise suitable and are also flexible in their use of native, non-spinescent species. Whether these atypical nest sites are equally suitable locations for breeding is not known.

We thank D. Bleakly, M. Merola, R. Robino, and E. Rockwell for reviewing earlier versions of this note.

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RECORDS OF THREE BAT SPECIES IN SOUTHEAST TEXAS

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During April, June, and December 1993, three species of bats representing distributional records were collected from southeastern Texas. These records include two species previously not reported from Brazos County and a third species representing the first known record of chiropterans from Galveston Island, Galveston County, Texas. The occurrence of the Brazos County individuals coincided with a cold front which moved into the College Station area from the east on 15 April 1993. Previous daytime highs for 12-14 April were in the 20° - 30°C range and nighttime lows in the 10° - 20°C range. But on 15 April the daytime high was 18°C with an overnight low of 7°C. Individuals of both species apparently were affected by the cold front and were forced to seek shelter on the sides of campus buildings. Specimens were deposited in the Texas Cooperative Wildlife Collection, Texas A&M University.

Pipistrellus subflavus subflavus (F. Cuvier, 1832).—On 16 April 1993 an adult female was captured on the Texas A&M University Campus, College Station, Brazos County. Prior to capture, this bat was observed flying near the entrance of the Sterling Evan's Library at approximately 0800 hr. This specimen represents the first record of the eastern pipistrelle in Brazos County. The nearest known locality of record is approximately 48 kilometers to the east in Walker County (Schmidly, 1991).

Subsequently, on 9 December 1993 four additional individuals (three females and one male) were collected in the attic of a house 9.6 kilometers S and 1.6 kilometers W College Station, Brazos County. The occurrence of these bats may suggest the possibility of a resident eastern pipistrelle population in Brazos County.

Lasiurus cinereus (Palisot de Beauvois, 1796).—An adult female hoary bat was captured on the Texas A&M University Campus, College Station, Brazos County, on 16 April 1993. This bat had been observed "roosting" on a brick wall for about 36 hours prior to capture and apparently had entered a state of torpor as a result of the low ambient temperatures. This specimen represents the first record of the hoary bat in Brazos County. The nearest recorded locality is approximately 60 kilometers to the southeast in Montgomery County (Schmidly, 1991).

Lasiurus intermedius floridanus H. Allen, 1862.—On 14 June 1993 an adult female with three pups (two male and one female) and an unrelated male pup were captured near Galveston Fire Station No. 5, 1104 56th Street, Galveston Island, Galveston County. These bats were collected from a fan palm tree that was cut down on the fire station property. In addition to these reported specimens, several other individuals were observed flying from the tree as it was being felled. These specimens represent the first recorded occurrence of this bat species on Galveston Island and suggest a possible resident population.

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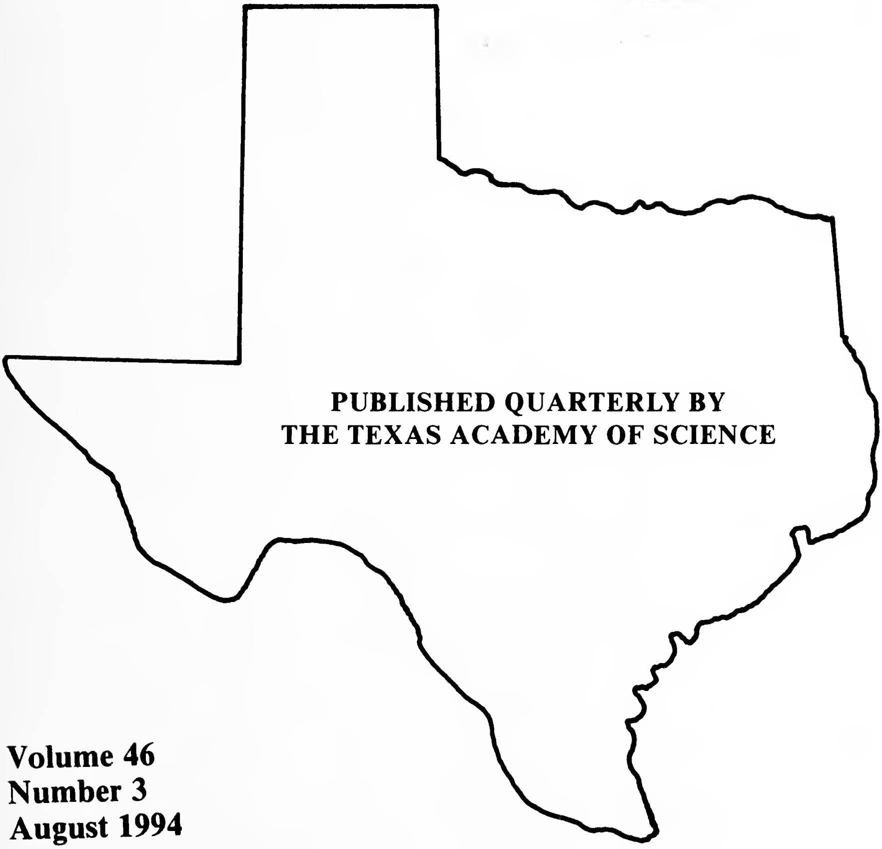

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MORPHOMETRIC VARIATION IN THIRTEEN-LINED GROUND SQUIRRELS, *SPERMOPHILUS TRIDECEMLINEATUS*, FROM WEST TEXAS

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Abstract.—Univariate and multivariate statistical tests were used to assess individual and secondary sexual morphological variation in a sample of 99 *Spermophilus tridecemlineatus* from northwestern Texas. Based on multiple analysis of variance results, variation in standard morphological measurements (condylobasal length, zygomatic breadth, mastoid breadth, and depth of skull) of adults was independent of age group, but dependent on sex. Discriminant function analysis correctly assigned 95% of the individuals to the correct sex when both cranial and external measurements were used, whereas 86% of the individuals were assigned correctly to sex based on cranial measurements only. Principal components analysis confirmed the presence of two distinct groups based on sex; a combination of four cranial and five external measurements accounted for 95% of the variation between sexes. Consequently, sexes should be analyzed separately when addressing systematic questions in this taxon from this area. *Key words: Spermophilus tridecemlineatus*; 13-lined ground squirrel; cranial variation; Texas.

The 13-lined ground squirrel, *Spermophilus tridecemlineatus*, inhabits a broad geographic area in the central United States. It occurs from Arizona in the south, and Montana in the northwest, eastward to Ohio. Southwardly, the range of this sciurid approaches the Gulf Coast of Texas, and northwardly, the prairie provinces of Canada. In Texas, *S. tridecemlineatus* is common, frequently found near cemeteries and parks, on golf courses, along mowed highway rights-of-way, and in other areas with relatively short, grassy vegetation.

Despite the relative abundance of this spermophile, awareness of any investigations that employ statistical techniques to document the amount of morphometric variation related to age or sex is not known. Some authors (Hoffmeister, 1986, 1989; Mumford and Whitaker, 1982) have reported external or cranial measurements, or both, including means, minima, maxima, and standard errors, but nothing more. Cothran's (1983) morphometric analysis primarily considered variation between *S. tridecemlineatus* and its congener, *S. mexicanus*. Nongeographic variation was not addressed for either species. This study, on the contrary, focused on individual and secondary sexual morphological variation in *Spermophilus tridecemlineatus arenicola* (Howell, 1928), from Lubbock, Lubbock Co., Texas.

At the latitude of Lubbock (33°34′ N, 101°49′W), this ground squirrel hibernates from four and a half to five and a half months each

TABLE 1.—Comparative cranial and external measurements (in millimeters) for males and females (age groups 1 and 2) of *Spermophilus tridecemlineatus arenicola* from Lubbock County, Texas.

Sex	*n*	*X* + 1 *SD*	Minimum-Maximum	*CV*
Condylobasal length				
M	42	37.1 ± 1.13	34.6 − 39.4	3.04
F	53	35.9 ± 1.24	32.7 − 38.9	3.47
Zygomatic breadth				
M	42	24.5 ± 0.92	22.6 − 26.3	3.74
F	53	23.4 ± 0.98	20.5 − 25.4	4.21
Postorbital constriction				
M	42	11.9 ± 0.48	10.9 − 13.1	4.07
F	53	11.9 ± 0.61	10.5 − 13.2	5.14
Least interorbital constriction				
M	42	8.3 ± 0.49	7.4 − 9.2	5.87
F	53	8.1 ± 0.45	7.1 − 9.2	5.58
Mastoid breadth				
M	42	18.9 ± 0.71	17.5 − 20.7	3.76
F	53	18.3 ± 0.75	16.4 − 19.9	4.11
Depth of skull				
M	42	17.6 ± 0.47	16.6 − 18.4	2.68
F	53	16.9 ± 0.52	15.6 − 18.0	3.08
Breadth across upper molars				
M	42	10.6 ± 0.43	9.8 − 11.4	4.04
F	53	10.5 ± 0.33	9.7 − 11.1	3.12
Alveolar length of maxillary toothrow				
M	42	7.5 ± 0.34	6.8 − 8.4	4.51
F	53	7.5 ± 0.25	6.8 − 8.0	3.31
Alveolar length of mandibular toothrow				
M	42	7.0 ± 0.33	6.2 − 7.6	4.79
F	53	7.0 ± 0.26	6.4 − 7.5	3.71
Total length				
M	39	265.4 ± 11.89	236.0 − 293.0	4.48
F	46	249.9 ± 13.81	205.0 − 276.0	5.52
Length of tail				
M	39	92.9 ± 8.01	74.0 − 107.0	8.62
F	46	88.8 ± 8.61	54.0 − 102.0	9.69
Length of hind foot				
M	42	34.9 ± 1.06	33.0 − 37.0	3.04
F	53	33.6 ± 1.55	30.0 − 36.0	4.61

TABLE 1. Continued

		Length of ear		
M	42	11.7 ± 0.60	10.0 − 13.0	5.12
F	53	11.0 ± 0.64	9.0 − 12.0	5.82
		Weight		
M	42	161.0 ± 24.2	112.0 − 235.0	15.03
F	53	109.8 ± 17.7	73.0 − 155.0	16.12

year. Variation in length of hibernation depends on age and sex of the squirrel, and to a certain degree, severity of weather (some individuals may be active during prolonged mid-winter warm spells). In any event, because of seasonal inactivity, tooth wear might allow us to assign individuals to discrete age groups, especially if all specimens were obtained shortly after emergence from hibernation, as no young are born until after emergence.

MATERIALS AND METHODS

Spermophilus tridecemlineatus is abundant in preferred habitats (Evans, 1951; Hall, 1955; Jones, 1964) in the Lubbock area. Specimens were collected from city parks and golf courses in Lubbock, and from open areas on the campuses of Texas Tech University and Lubbock Christian University, as well as from a golf course at Reese Air Force Base, just to the west of town. Ninety-nine individuals were collected from flooded burrows during the three-week period of 16 March to 4 April 1990.

External measurements were taken by the three authors; however, all nine cranial dimensions were taken by Hall, using a pair of Fowler digital calipers calibrated to 0.01 mm. Standard cranial characters (after DeBlase and Martin, 1981) were measured on each specimen and include condylobasal length (CBL), zygomatic breadth (ZB), postorbital constriction (PC), least interorbital breadth (LIB), mastoid breadth (MB), greatest breadth across upper molars (BRMAX), depth of skull (DS), alveolar length of maxillary toothrow (MXTR), and alveolar length of mandibular toothrow (MNTR). Post-cranial measurements included total length (TL), length of tail (TV), length of hind foot (HF), length of ear (EAR), and weight (WT) (Table 1).

Univariate and multivariate statistical tests were conducted on a MAC LC II and a VAX 860, available through Academic Computer Services at Texas Tech University and User Services at Southwest Texas State University. All statistical analyses were preformed utilizing SPSS (SPSS Inc. 1990) and SPSS-X (SPSS Inc., 1988) statistical packages.

AGE DETERMINATION

Specimens were assigned to age groups on the basis of wear on upper cheekteeth, last premolar (P4), and first and second molars (M1, M2), utilizing comparative rates of wear on P3 and M3 only as needed. Using these criteria, four age groups were identified, which were suspected to represent annual cohorts characterized as follows: 1) young adults—slight to moderate wear on paracone and metacone of P4, M1, and M2, but protocone only slightly worn, P3 with virtually no (or only slight) wear; 2) adults—distinct wear on cones of P4 and

TABLE 2.—Results of principal components analysis (Program FACTOR, SPSS Inc., 1988) based on nine cranial characters for males and females separately (Table 1.) Unique variation attributed to each variable and cumulative percentage of variance are given.

Variable	Males		Females	
	Unique variance	Cumulative variance	Unique variance	Cumulative variance
Condylobasal length	53.7	53.7	60.2	60.2
Zygomatic breadth	17.2	70.9	13.8	74.0
Postorbital constriction	11.3	82.2	8.1	82.1
Interorbital constriction	6.0	88.2	5.6	87.7
Mastoid breadth	4.0	92.2	4.4	92.1
Depth of skull	1.7	99.0	2.0	98.8
Breadth across molars	3.0	95.2	2.6	94.7
Length of max. toothrow	2.1	97.3	2.1	96.8
Length of man. toothrow	1.0	100.0	1.2	100.0

all molars but individual cones clearly separated from each other except on M3 (wear had obliterated divisions between some cones and styles), P3 moderately worn; 3) adults—cones no longer distinct on molars, some cone integrity remains on P4, top occlusal surface of P3 nearly flattened; 4) old adults—P3 appearing as a flattened peg, P4-M3 heavily worn, cones distinct (if present) only on labial margin of teeth.

It was suspected that squirrels in age group 1 represented yearlings. Those in age group 2 most likely were two years old and those in age group 3 may have been three years old. One individual, identified as belonging to age group 4, probably was four years old or older (a greater degree of wear has been seen on teeth of a few individuals of this species not used in this sample). The number of individuals in age groups 1 to 3 totaled 98, with 33 males and 48 females in group 1, seven males and seven females in group 2, and one male and two females in group 3. Greatest degree of variability in tooth wear occurred in age group 1. This may be the result of differential birth dates during spring, and different dates of entry into hibernation in late summer and early autumn. Second litters, unknown in the northern part of the range of *S. tridecemlineatus*, are not uncommon in northern Texas (McCarley, 1966).

RESULTS AND DISCUSSION

Multivariate analysis of variance (Program MANOVA, SPSS Inc., 1988, 1990) was used to analyze cranial and external measurements, with sex and age as the main effects (Willig et al., 1986). A significant difference exists between sexes ($P < 0.000$), but no significant difference occurs between age groups 1 and 2 ($P = 0.841$). The absence of a significant interaction between sex and age ($P = 0.496$) suggests that

TABLE 3.—Sorted factor matrix (varimax rotation) for males and females separately, based on nine cranial characters of *Spermophilus tridecemlineatus*. Bold loadings indicate a strong correlation of a character with a PC axis. See text for abbreviations.

Variables	Males			Females	
	PC1	PC2	PC3	PC1	PC2
ZB	**0.83037**	0.29241	0.10759	**0.74488**	0.48660
CBL	**0.80554**	0.37440	−0.11552	**0.72056**	0.54451
LIB	**0.80046**	−0.27296	−0.07355	**0.77224**	0.20253
MB	**0.79371**	0.31295	0.17453	**0.77118**	0.46756
DS	**0.78106**	0.28495	0.31077	**0.77827**	0.47030
BRMAX	**0.68820**	0.56969	−0.00323	0.31506	**0.76670**
MNTR	0.21741	**0.93117**	−0.02208	0.10782	**0.90637**
MXTR	0.15464	**0.91957**	−0.01031	0.19688	**0.77637**
PC	0.08186	−0.05200	**0.97512**	**0.78586**	−0.08143
Percent variation	53.7	17.2	11.2	60.2	13.8

each factor affects morphology in a constant fashion. Individuals from age groups 3 and 4 were excluded from analyses because of small sample sizes (three and one, respectively). Univariate tests, run concurrent with MANOVA, suggested that all external measurements and four cranial measurements (CBL, ZB, MB, and DS) likely contributed to the significant difference between sexes.

Discriminant function analysis (Program DISCRIMINANT, SPSS Inc., 1988, 1990), was used to assess whether individuals could be correctly assigned to age groups based on the aforementioned character suite. Less than 65% of the individuals were correctly assigned to age groups based on all morphometric characteristics, and only 57% of the individuals if only cranial measurements were used. This suggests that age does not significantly contribute to morphological differences between individuals provided all specimens are in their second year of growth.

Discriminant function analysis (DFA), using sex as the grouping criterion, correctly classified 95% of the individuals. Efficacy dropped slightly, to 86%, if only cranial measurements were used. Weight contributed heavily to distinguishing between sexes, followed closely by DS, BRMAX, and MB.

Principal components analysis (Program FACTOR, SPSS Inc., 1988, 1990) was used to corroborate the findings of DFA; external measurements alone accounted for 86% of the variation among individuals. When individuals were plotted on principal component axes, groupings of males were relatively distinct from females. When only cranial measurements were analyzed, CBL, ZB, PC, LIB, MB, and BRMAX accounted for 95% of the interindividual variation (Tables 2 and 3).

The results of this study suggests that sex is a major cause of morphological variation in 13-lined ground squirrels in West Texas. Sexes should be analyzed separately when addressing systematic questions concerning *Spermophilus tridecemlineatus* in the future.

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VEGETATION RELATIONSHIPS TO WATER GRADIENT IN A CONSTRUCTED FRESHWATER WETLAND NEAR BRAZORIA, TEXAS

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Abstract.—Data on plant distribution were collected along 5 point-intercept transects in different water depths of a constructed freshwater impoundment on the San Bernard National Wildlife Refuge. Patterns of distribution and resultant statistical correlations reflect the dominance of water-tolerant species and genera in the regularly flooded portion, and species that tolerate only periodic flooding in the drier reaches. Yearly variation in rainfall and pond water levels created diverse conditions for plant establishment and survival, and species composition varied considerably on transects in different water depths. Although plant richness seemed to increase over time, the establishment and subsequent spread of cattail modified cover-water patterns and threatened structural diversity in deeper water areas. Potential management options include basin design and water management, but better life-history information is essential for many of the dominant plants.

Based on studies of both impounded (Palmisano, 1972) and natural Gulf Coast wetlands (Cottam & Glazener, 1959), freshwater marshes are especially attractive to migrant and wintering waterfowl and nesting waterbirds; thus, managers of coastal wildlife refuges often construct impoundments to provide freshwater in areas dominated by saline marsh. However, management of suitable vegetation-water interspersion in such water areas may be complicated by plant dominants such as cattail (*Typha* spp.). Thus, understanding plant water requirements and patterns of succession are valuable not only to aid in creating ideal food and cover conditions for waterbirds but to minimize loss of vegetation structure due to plant dominance. Additionally, interest in wetland restoration has created a need for better information on factors influencing wetland plant distribution, survival, and community succession in coastal systems.

The objectives of the study were to: 1.) examine plant distribution and community gradients in relation to general patterns of water depth, and 2.) document year-to-year vegetation dynamics over water regimes that might reveal patterns of succession useful in the development of strategies for vegetation management in a highly variable climatic regime.

Study Area

San Bernard National Wildlife Refuge, a coastal refuge now totaling

9,900 ha, was purchased starting in 1969 by acquisition of several small ranches used by lesser snow geese (*Chen caerulescens caerulescens*) and other wintering waterfowl. Because mineral rights remained with the original owners, a road was constructed in 1976 to a well-drilling site in the saline marsh. To avoid the soft substrate, this roadbed angled along higher ground, crossing several freshwater flowages into the estuary, and then turned directly into the marsh. Conduits allowed some water passage under the road, but an additional wing dam prevented the remainder from diverting eastward around the roadbed and into the estuarine wetland. The resulting dam formed an 81-ha freshwater impoundment called Moccasin Pond (Fig. 1). Subsequent construction resulted in a "U"-shaped dam which also serves as a road around the pool. The borrow ditch is on the pond side of the dam, insuring some deep-water habitats even when the pond area dries completely. Moccasin Pond currently has numerous downslope water-control structures in the southern and eastern levees. Because of the chance of drying due to reduced rainfall combined with the normal high heat, evaporation, and transpiration in summer, these structures are closed during late spring to hold water for nesting birds. This impoundment not only traps fresh water, but the dam also prevents seawater intrusion during most hurricanes; salinity ranges from 0 to 3 ppt, dependent upon volume (Barry Grand, unpubl. data).

Aerial photographs from the pre-impoundment period suggest that the original plant species along the flowage have changed very little in the drier portion of the pond, and those areas holding the deepest water were impacted most. During the study period, even very shallow open-water areas of Moccasin Pond supported dense stands of submergent plants, mainly bladderwort (*Utricularia* spp.) (plant names from Correll and Correll, 1975), common water-nymph or bushy pondweed (*Najas guadalupensis*), common hornwort or coontail (*Ceratophyllum demersum*), and several species of *Potamogeton*. There was a small stand of Mexican water lily (*Nymphaea mexicana*) in the ditch at the eastern extension of the dam that always held water. In 1984, the only extensive strands of southern cattail (*T. latifolia*) occurred along upslope ditches where drydown was common in early- to mid-summer. Then, from more regularly flooded to drier areas, dominant vegetation graded from seashore paspalum (*Paspalum vaginatum*) to saltmeadow cordgrass (*Spartina patens*), spiny aster (*Leucosyris spinosa* = *Aster spinosus*) and sea ox-eye daisy (*Borrichia frutescens*), Gulf cordgrass (*S. spartinae*), and finally groundsel-tree (*Baccharis halimifolia*) at the western pond margin (Fig. 1). The close relationship of the above species to water has resulted in their use as wetland indicators (Reed, 1988).

Because of concerns that deeper water areas near the dam were

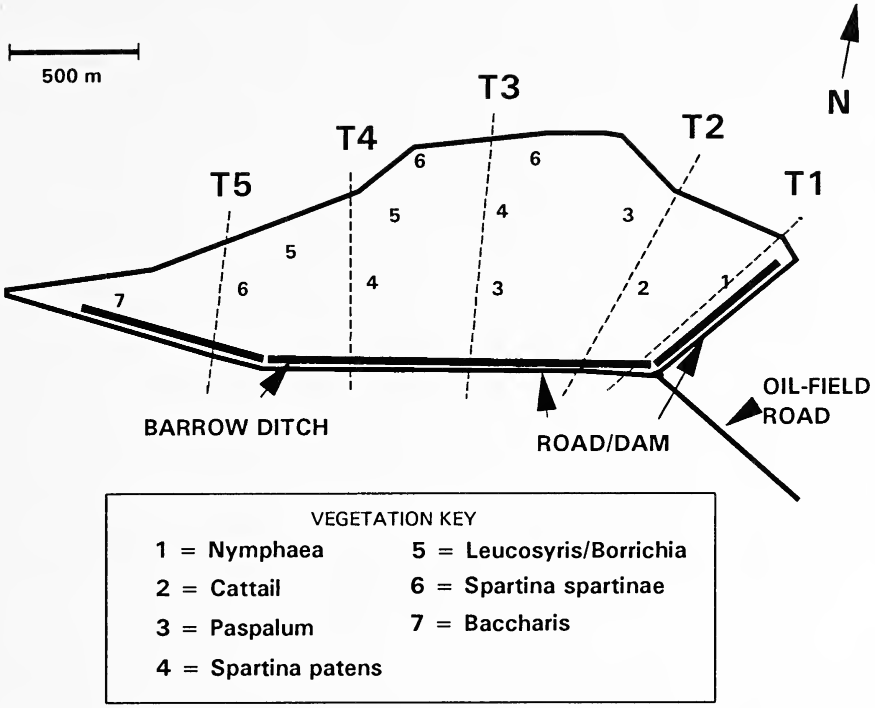

FIGURE 1. Outline of Moccasin Pond showing locations of five point-intercept transects, the borrow ditch, general pattern of plant distribution at the start of the project, and relationship of the pond to Oil-field Road.

becoming dominated with cattail, several methods were attempted by refuge personnel to slow population expansion and reduce density. These included mowing, disking, and "mashing" small areas with a marsh buggy, with the intent of submerging the stalk ends after breakage to reduce regrowth (Weller, 1975).

In 1988, a fire burned the drier, western portion of Moccasin Pond dominated by *Baccharis*, *Spartina spartinae*, and *S. patens*, but impacts of this on the vegetation survey of 1991 seem unlikely because perennial plants tend to resprout and plant height and maturity are more affected than species composition (Tester and Marshall, 1962).

METHODS

Minimal resources limited observations to one plant survey per sampling year, but general observations on water regimes were made during other research and management activities on the area. The initial survey was done in 1984 by Texas A&M University student Suzanne Coltman, who served as an intern at San Bernard National Wildlife Refuge, and refuge biologist Michael Lange (Coltman, 1985). Subsequent surveys were done in 1985-1987 and 1991 by various students during related waterbird and vegetation studies.

Vegetation was assessed via 5 transects about equally spaced from the deep-water *Typha* zone near the dam to the upper *Spartina spartinae* zone (Fig. 1), but avoiding the solid stands of groundsel-tree at the drier upland end. Point-intercept transects were used with observations at 1 m intervals. Plant species occurring under or over the point on the tape were recorded; thus, >1 plant per point regularly occurred. Only aquatic or wetland plants that were common and dominated large areas of the pond were identified to species; less common species were grouped by genera. Data were recorded in July after maturation of most species, and when water levels usually were at their minimal level. For presentation, plant data were converted to percent of points occupied to avoid complications resulting from minor year-to-year variation in transect lengths.

Open water, bare substrate, and plant litter were recorded as appropriate at 1-m intervals; water depth was recorded every 10 m except on the initial survey in 1984 when the entire area was dry. A water gauge was established in a ditch on Moccasin Pond in 1984 to provide year-to-year comparison of water depth, but recording interval was highly variable due to personnel changes and distance to the site.

Vegetation surveys were made annually during a period of significant variation in rainfall and water depth during 1984 through 1987, and again in 1991 after several dry years followed by very heavy rainfall.

RESULTS

Water Regimes

In most years, staff were not on site continuously so water-gauge readings lacked continuity, but available records were averaged to provide an index for each year. The typical annual pattern of water availability and depth is reflected in 1986 water-gauge readings made at about 2-week intervals (Fig. 2). Moccasin Pond typically was deepest in spring and low to dry by mid- to late-summer, but with still greater peaks in fall of some years due to tropical low-pressure systems (Fig. 2). Such high water levels often were retained overwinter due to reduced transpiration and evaporation.

Rainfall data for 1984-1987 and 1991 from refuge files (Fig. 3) show the general patterns that created completely dry conditions during early summer in 1984 (staff gauge x = 0), with a tropical rain in fall that elevated water levels, and that carried over into 1985 as reflected on transects (x = 51.2 cm [Fig. 4]). The level gradually declined during fall, drying early in 1986 (water gauge x = 38.4 cm) followed by heavy fall rains. Then several below-normal rainfall years produced erratic but generally lower pond water levels (for which records are not available) until more normal rainfall combined with water management in 1991 increased mean pond level (water gauge x = 76.2 cm).

Spatial Patterns of Plant Distribution in Relation to Water Depth

Dominant plants and major groups of related taxa are shown as percent of total points at which a species occurred by transcet and year (Table 1); less common species are clustered by life form. Based on

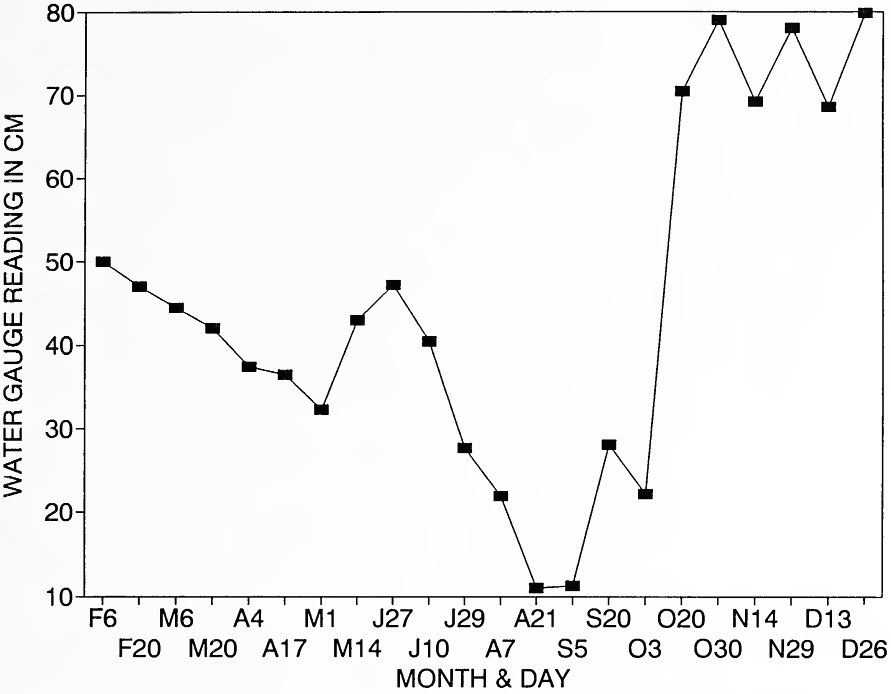

FIGURE 2. Water level changes in Moccasin Pond based on water-gauge readings, Summer 1986, showing typical spring high and drydown, followed by Fall increase due to rainfall from tropical depressions in September and October (see rainfall data in Fig. 3). Pond data recorded by B. Grand.

water depths recorded at 10-m intervals along point-intercept transects, water depth varied each year (Fig. 4) with the extreme in 1984 when the area was dry. To provide a better comparison of depth gradient within the pond, a mean was calculated for the 4 wet years for each transect, providing an index value (in cm) for all years for each transect: 1 = 27.9, 2 = 25.6, 3 = 13.2, 4 = 7.2, and 5 = 0.3. Transects 1 and 2 differed little in depth, but the remaining 3 were progressively more shallow (Fig. 4).

Statistical analyses of plant/water relationships were limited for 2 reasons. First, distribution of many species was limited, probably due to water tolerances, to $\leq$ 3 transects (e.g., *Leucosyris, Borrichia*, and submergent species) and others were limited to the later years after colonization of newly flooded habitats (e.g., *Eleocharis*, duckweed, and *Nymphaea*). Consequently, there are many zeros in the data (Table 1). Secondly, some statisticans do not regard individual points in a given transect in a given year independent of each other. To address these problems, analyses were restricted to those portions of the data table where sufficient observations were made. Specifically, the table

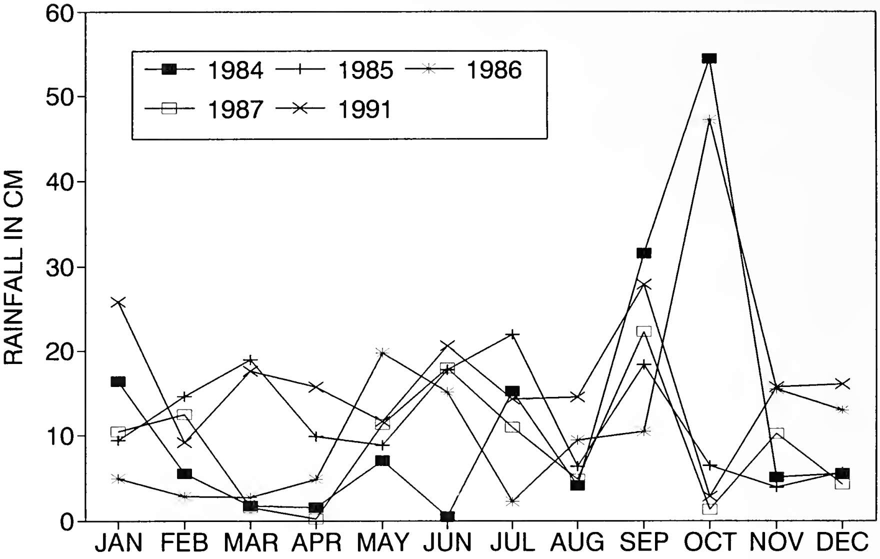

Figure 3. Rainfall data for San Bernard National Wildlife Refuge at Brazoria, Texas, 1984-1987 and 1991.

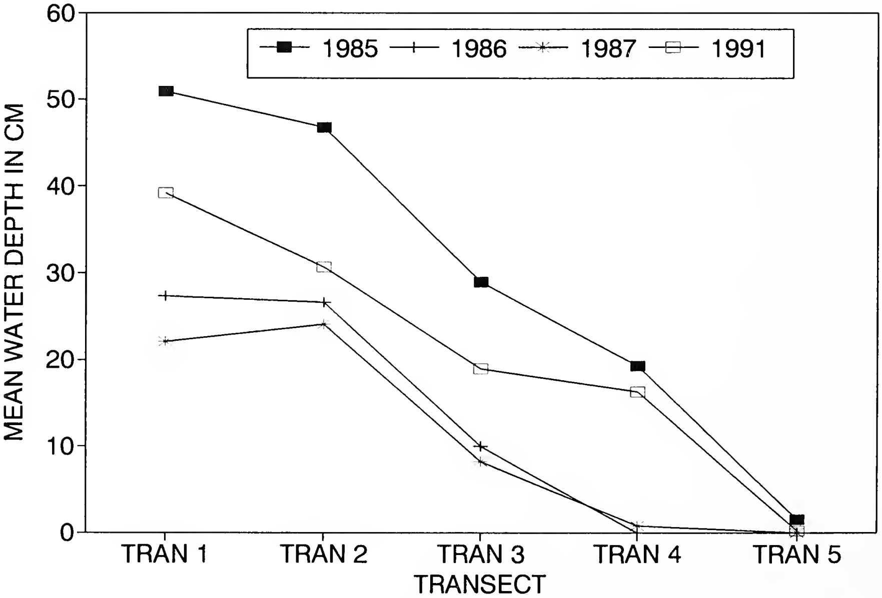

Figure 4. Mean water depth from data recorded on point-intercept transects 1 (deep) to 5 (shallow), 1985-1987 and 1991. All transects were dry in 1984.

Table 1. Percent occurrence of dominant species by points of five point-intercept transects and by year, generally ordered from dry to wetter requirements. For each plant species, differences significant at the p <0.05 level are indicated for year (a), transect (b), and year X transect interaction (c). Plants not tested (d).

	Transect Number				
Taxon/Year	1	2	3	4	5
Baccharis hamilifolia (d)					
1984	0	0	0	0	2.0
1985	0	0	0	0	0.5
1986	0	0	0.1	0	0.7
1987	0	0	0	0	0.7
1991	0	0	0	0	7.5
Leucosyris spinosa (a,b,c)					
1984	0	0	0	14.8	12.9
1985	0	0	0	12.7	9.3
1986	0	0	0	11.3	16.7
1987	0	0	0	19.1	15.6
1991	0	0	0	1.2	16.4
Borrichia frutescens (a,b,c)					
1984	0	0	0	34.3	21.8
1985	0	0	0	7.5	6.0
1986	0	0	0	24.8	17.9
1987	0	0	0	32.7	17.5
1991	0	0	0	5.0	9.1
Spartina spartinae (a,b,c)					
1984	13.7	9.0	8.2	16.3	87.5
1985	15.4	9.5	7.8	12.2	80.3
1986	15.8	8.9	12.1	10.0	79.4
1987	15.8	9.2	11.3	12.0	78.3
1991	11.6	5.7	5.7	0.3	65.9
Spartina patens (a,b,c)					
1984	0	0	73.8	70.6	1.4
1985	0	0.1	57.2	81.8	16.7
1986	0.3	0	77.1	93.0	22.3
1987	0	0.4	63.7	84.1	13.3
1991	4.1	1.0	43.5	40.2	24.5
Sesbania drummondi (a,b,c)					
1984	0	0	11.4	0.2	0
1985	0	0	21.7	1.3	0
1986	0.6	0	20.9	1.8	0
1987	0	0	22.9	4.3	0
1991	0	0	0	0	0
Eleocharis spp. (a,c)					
1984	0	0.1	0	0	0
1985	0	0	0	0	0
1986	2.6	2.8	13.7	6.1	3.5
1987	3.5	2.4	0.7	0.3	0.2
1991	9.2	6.2	23.1	59.8	10.7
Cyperus spp. (b,c)					
1984	0	0	5.6	32.3	0.5
1985	0	0.1	17.2	15.6	0

TABLE 1. Continued

1986	0.5	0.1	15.3	36.9	3.0
1987	0.9	0.6	28.5	65.5	1.9
1991	0.3	1.0	16.9	17.8	16.4
Carex spp. (d)					
1984	0	0	5.6	0.2	0
1985	0	0	0	0	0
1986	0	0.1	6.7	0.2	0
1987	0	0	11.0	1.1	0
1991	0	0	0	0	0
Echinodorus rostratus (d)					
1984	0.3	0.1	0	0	0
1985	3.9	5.4	0	0	2.3
1986	0.3	0	0	0.2	0
1987	0	1.4	0	0.2	0
1991	5.9	1.4	6.1	6.9	0
Paspalum spp. (b,c)					
1984	44.1	79.2	13.9	5.7	0
1985	30.7	61.0	17.9	5.6	0.7
1986	27.1	68.9	20.3	3.6	0.2
1987	37.0	67.5	28.2	12.3	0.7
1991	0	16.4	2.9	1.5	0.5
Typha spp. (a,b)					
1984	20.9	10.8	0	0	0
1985	12.7	8.9	0	0	0
1986	31.3	16.9	0	0	0
1987	39.1	15.5	0.1	0	0
1991	55.3	22.8	25.1	1.9	0
Nymphaea mexicana (d)					
1984	0	0	0	0	0
1985	0	0	0	0	0
1986	0	0	0	0	0
1987	0.2	0	0	0	0
1991	10.6	1.5	0	0	0
Utricularia spp. (a,c)					
1984	0	0	0	0	0
1985	0.5	0.4	0.1	0	0.7
1986	7.4	14.5	0	0	0
1987	5.7	1.3	0	0	0
1991	35.0	17.1	9.2	12.5	0
Other Submergents (a)					
1984	0	0	0	0	0
1985	21.9	21.3	0	0	0
1986	17.3	13.8	0	0	0
1987	16.9	16.3	0	0	0
1991	36.3	36.7	8.5	0	0
Duckweed (d)					
1984	0	0	0	0	0
1985	0	0	0.2	0	0
1986	29.1	0	0	0	0
1987	37.4	4.5	2.4	0	0
1991	42.9	31.1	7.9	0	0

TABLE 1. Continued

Filamentous Algae (a,b,c)					
1984	0	0	0	0	0
1985	42.9	28.2	0	0	0
1986	8.0	13.6	0	0	0
1987	18.1	14.3	0	0	0
1991	23.6	9.1	13.8	0	0
Other Plants (d)					
1984	17.3	3.5	15.9	2.5	0
1985	32.7	2.3	26.3	3.6	5.8
1986	9.5	2.4	12.4	5.2	12.8
1987	9.2	1.7	12.8	12.0	15.6
1991	4.9	12.3	3.4	48.3	15.9
Detritus (d)					
1984	0.3	0	0	0	0
1985	0	0	0	0.3	0
1986	0	0	0	0	0
1987	0	0	1.1	0	0.5
1991	0	0.8	4.4	1.2	0.5
Soil/Mudflats (d)					
1984	22.9	16.7	0	0	0
1985	0	0	0	0	0
1986	0	0	0.1	0	0
1987	0	0	0	0	0
1991	0	0	0.7	0	0
Open Water (d)					
1984	0	0	0	0	0
1985	12.5	4.9	0.1	3.1	0.2
1986	11.8	4.7	0.2	0	0
1987	6.1	1.5	0	0	0
1991	0	19.3	3.6	2.4	0

containing years 1984-1991 and transects 1-5 ({84-91 X 1-5}) for *Spartina spartinae, Cyperus,* and *Paspalum,* {84-91 X 3-5} for *Spartina patens,* {84-91 X 4-5} for *Leucosyris* and *Borrichia,* {84-91 X 1-2} for *Typha,* {84-87 X 3-4} for *Sesbania,* {85-91 X 1-2} for *Utricularia,* Algae, and other submergents, and {86-91 X 1-5} for *Eleocharis* were analyzed. Other species were not tested statistically. The number of points on each transect where a particular species occurred was adjusted to account for year-to-year differences in transect length by modification to the shortest length. Log-linear models were constructed for each species using the adjusted counts and Proc Catmod in SAS (SAS 1990) to examine the effects of year, transect, and their interaction (Table 1).

Water-tolerant plant species were clustered at the deep-water end and those favoring long dry periods were on less commonly flooded ground in shallow areas or along pond margins (Table 1, Fig. 1). Plant dominants in the deeper water transects 1 and 2 included lateral stands of *S. spartinae* on high ground, but mainly water-tolerant species like

TABLE 2. Spearman rank correlations showing positive relationships between deeper-water taxa and negative correlations between deeper and more terrestrial species, based on percent of occupied points.

	Spartina spartinae	*Leucosyris spinosa*	*Borrichia frutescens*	*Spartina patens*	*Paspalum* spp.	*Typha* spp.	Submergent	*Nymphaea mexicana*
Spartina spartinae	1.0000							
Leucosyris spinosa	0.5525	1.0000						
Borrichia frutescens	0.5134	0.9628	1.0000					
Spartina patens	-0.0827	0.4603	0.5056	1.0000				
Paspalum spp.	-0.3800	-0.6702	-0.6407	-0.4758	1.0000			
Typha spp	-0.3287	-0.6927	-0.6927	-0.6733	0.4195	1.0000		
Submergent	-0.2337	-0.5684	-0.5684	-0.5751	0.3083	0.7975	1.0000	
Nymphaea mexicana	-0.1111	-0.2883	-0.2884	-0.2626	-0.0848	0.5610	0.6008	1.0000

Paspalum vaginatum, Typha domingensis, Utricularia spp. and other submergents, filamentous algae, and water lily. Mid-depth transects 3 and 4 were dominated by plants like *Spartina patens* that favor periodical over permanent flooding, and moist-soil plants like *Cyperus* spp. and *Sesbania* spp., with *Typha* spp. (mainly *T. latifolia*) increasing only in later years. *Leucosyris* and *Borrichia* were not abundant on the latter 2 transects but were dominants in the least-often flooded transect 5. The latter was the only transect with *Baccharis.*

Using a nonparametric Spearman rank correlation, positive correlations (Table 2) occurred between the more terrestrial dominants such as *Leucosyris, Borrichia* and *Spartina spartinae* and, in most cases, *S. patens,* with negative correlations of those species with water-tolerant *Typha, Paspalum,* lily and submergents. As expected, positive correlations occurred among the latter species.

Temporal and Spatial Distribution of Dominant Plants

Numerous plant species changed in distribution over the 7-year study period, with a general pattern of decreasing terrestrial species and increasing water-tolerant species (Table 1). *Leuscosyris* and *Borrichia* were limited to drier transects 4 and 5 intermixed with *S. spartinae* and some *Baccharis* on transect 5; their incidence was variable over the first 4 years, but declined in the wetter year of 1991. *Spartina spartinae* occurred in all transects because it is abundant on higher, less-flooded edges of all transects, but was a near-continuous dominant on transect 5 at the western shallow end of the pond. Data from the first 4 years showed minor change but generally declining incidence, especially evident in the wet year of 1991.

Several plant taxa occupied the middle zone (transects 3 and 4) that was flooded in the wet spring but normally dried to moist-soil conditions by early summer: *Spartina patens, Sesbania, Eleocharis, Cyperus, Carex* and *Echinodorus. Eleocharis* increased over time, especially on drier transects in wetter years. Although *S. patens* also was found on deeper transects due to populations at the margins, flooding regimes seemed optimal for this species along all of transects 3 and 4. *Cyperus* was most prominent on transects 3 and 4 where it decreased in the wet year of 1991 but it increased on transect 5 which was flooded extensively that year. *Sesbania* occurred mainly on transects 3 and 4 and was essentially eliminated in the later years of the survey, perhaps because of lack of drawdown conditions conducive to germination.

The more regularly flooded conditions along transects 1 and 2 were ideal for *Paspalum vaginatum* but significant stands occurred also on transect 3. The more shallow area along transect 3 included some longtom (*P. lividum*) as well, but the 2 species were not separated in all years. Although a non-significant year effect ($p = 0.08$) was found, deep-water conditions of 1991 reduced stands of *Paspalum vaginatum* substantially on most transects but especially on transects 1 and 2 where water depths exceeded other years due to poor drainage associated with periodic storm flooding. *Typha,* which was most abundant on transect 1 and 2, spread to 3 and 4 by 1991. However, cattail was somewhat reduced by cutting patches late in 1984 and mashing down areas with a vehicle in 1987-88. Cattail expansion was even more dramatic than measured by the point-intercept data (Fig. 5). Water lilies also spread from their restricted location in the ditch (1984) into transect 1 by 1987, and into 2 by 1991. Submergents were represented by several genera, some of which (e.g. *Utricularia*) survived in very shallow water and occurred seasonally, but most were typical of the deeper water transects 1 and 2. All submergents were more abundant in the wetter year of 1991 and expanded from transects 1 and 2 into 3.

Based on the 18 groupings of genera and life forms used in analyzing the survey data, taxon richness was lowest in the dry year of 1984 ($x = 6.6$ taxa per transect), and increased to 8.6, 10.4, 10.6 during 1985 through 1987, respectively, and to 11.4 in the very wet year of 1991. A log-linear model indicated that richness increased significantly from 1984 to 1991 ($p < 0.01$) but was similar on all transects ($p = 0.91$).

DISCUSSION

These observations demonstrate patterns of plant distribution reflecting water depth gradients within various portions of this wetland, but also show an increase in species richness probably due to water dynamics or rate of pioneering over time. There was a general increase of water-tolerant plants over the sturdy period which synchronized with generally wetter conditions in the pond. However, causes of vegetation dynamics at each site cannot be determined on the basis of these data. Plant responses such as seeding and vegetative propagation to hydroperiod and mean water depth could not be studied with only annual observations, but the data suggest the need for more detailed studies of seeding requirements and water depth tolerance of these plants.

It seems probable that the extreme drawdown in May of 1984 provided opportunity for mass seeding as well as rhizome spread of cattails from plants in the deepwater areas and borrow ditch. The two species of cattail are known to favor different water depths (Grace, 1989), making the entire pond suitable for either species and their hybrids. Cattail control programs on Moccasin Pond did influence

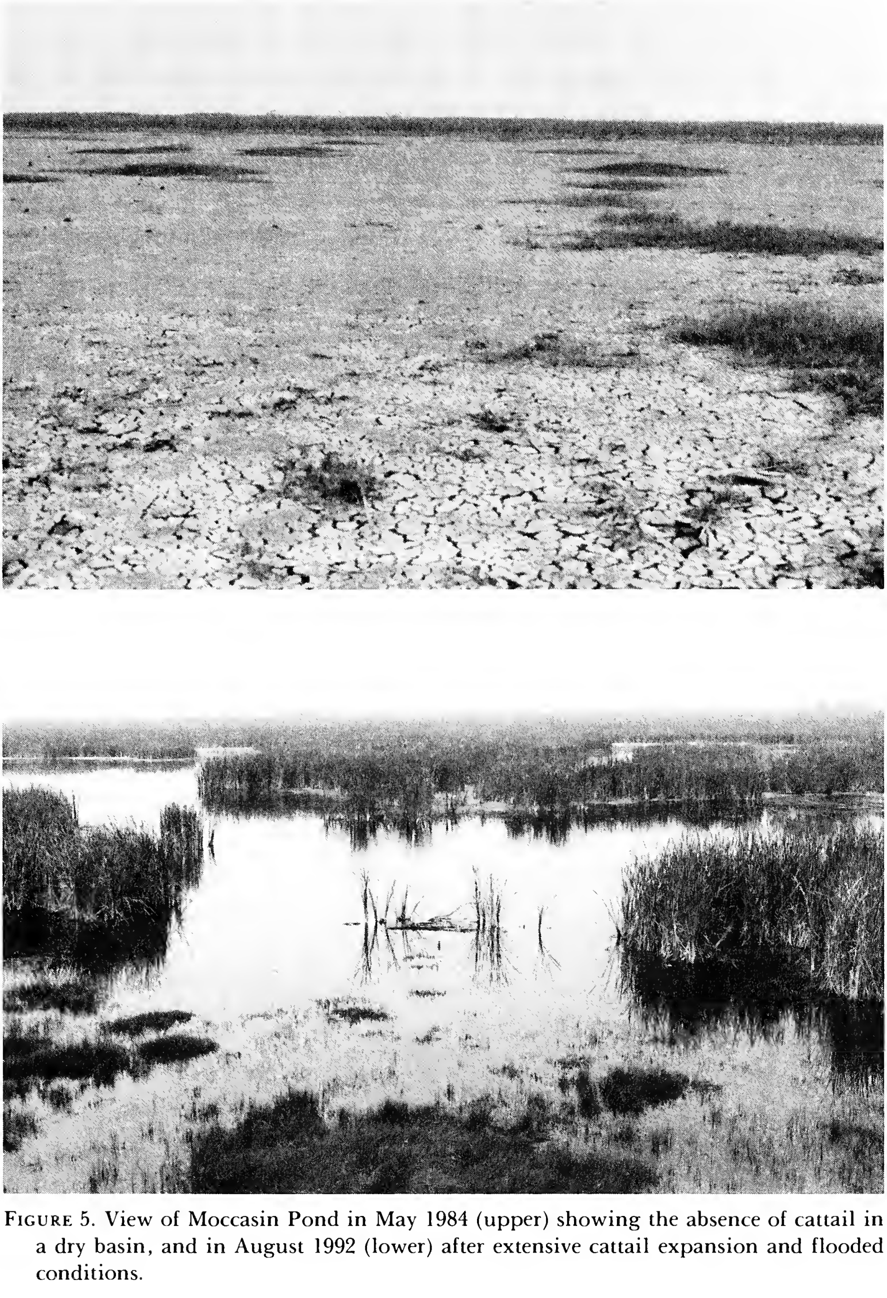

FIGURE 5. View of Moccasin Pond in May 1984 (upper) showing the absence of cattail in a dry basin, and in August 1992 (lower) after extensive cattail expansion and flooded conditions.

incidence along some transects. Mowing and disking occurred after the first plant survey in 1984, but cattail had regrown to a height of 0.9 m by April of 1985. However, these efforts involved less than 6 ha, mainly along the deep-water transects, which was reflected in reduced cattail recorded on transect 1 in 1985, with recovery by 1986.

Management of plant dominance problems is difficult if water-level control is not possible and water regimes allow a mass seeding event or promote one species by chance. The natural water regime of Moccasin pond (Fig. 2) creates a strong chance of drydown and seeding of emergent plants in summer, followed by the likelihood of summer rains that encourage growth and survival. Prevention of extensive germination requires either a.) dry conditions that reduce seedling survival, or b.) water availability at all seasons to prevent drydown during cattail germination periods. If intensive management is required, flooding after cutting or mashing (Weller, 1975), or regular drying and burning (Mallik and Wein, 1986) can be used. However, there are serious problems in attempting to use the available water-control structures to manage plant growth and seed production via drawdown unless we have critically needed information on plant life history (e.g., seasonality of germination) to perfect such management stategies as are used in areas farther north (Fredrickson and Taylor, 1982).

There was an increase in species richness recorded during the study, suggesting that plant diversity is influenced by the age of the wetland or that various water conditions allowed germination and growth of different species.

Because of the incidence of reservoir construction and wetland restoration along the Texas coast, these data provide information on potential plant species likely to occur, and suggest patterns of water depth and basin contour likely to dictate plant community response. It is clear that shallow areas like this impoundment will develop monotypic stands of cattail that reduce plant species richness and structural diversity over more regularly flooded areas of a wetland. This may be desirable in cases of wastewater management or erosion control; otherwise, design of basin configuration or development of suitable water supplies and other vegetation management strategies are essential to minimize this problem.

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WIDEBAND PHOTOMETRY OF NGC 7027

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ABSTRACT.—Wideband photometric measurements of NGC 7027 have been carried out at Texas A&M University Observatory and are summarized in this report. A solid-state photoelectric photometer along with Johnson B, V, R and I filters were used. The observed B, V, R and I magnitudes of NGC 7027 are +9.87 ± 0.05; +8.89 ± 0.01; +8.24 ± 0.01 and +8.21 ± 0.02 respectively.

Reverend T. W. Webb discovered the planetary nebula, NGC 7027, on November 14, 1879 (Webb, 1962; Jones, 1979). NGC 7027 is in the constellation Cygnus and has angular dimensions of 18 by 11 arc-seconds (Burnham, 1978). This nebula is at a distance of 1200 ± 200 parsecs (Pottasch, 1984). Its mass is one fifth that of the sun and is expanding at a rate of 18 km/s (Pottasch, 1984). Pottasch (1984) believes that the central star of NGC 7027 has a temperature of 300,000 K while Péquignot and Stasinska (1980) suggest a temperature of 170,000 K; the central star, however, is not visible (Aller, 1971).

Bowen and Wise (1939) measured the spectrum of NGC 7027 and were able to identify several elements. They noted, however, that many common metals were scarce or absent which led to the conclusion that the composition of this nebula is different from that of stars. More recently, Kaler and co-workers (1976) measured the spectrum of NGC 7027 in the range 3132 Å $\leq \lambda \leq$ 8665 Å and were able to determine the abundances of several elements including oxygen, carbon, nitrogen, silicon and hydrogen. Small carbon particles and carbon monoxide are believed to make up part of NGC 7027 (Aller, 1984).

In spite of the large amount of attention given to NGC 7027, it appears that its apparent magnitude is not well known. Magnitudes of 8.5 (Webb, 1962; Sulentic and Tifft, 1973); 9.0 (Burnham, 1978); 10.4 (Hirshfeld and Sinnott, 1985) and 10.5 (Dixon and Sonnerborn, 1980) have been reported. Due to the wide range of apparent magnitudes, it was decided to carry out a precise photometric study of this nebula.

A total of 68 photometric measurements of NGC 7027 are reported. Measurements were made through the Johnson B, V, R and I filters. The equipment used and experimental method are first described, and is then followed by a discussion of the results.

METHOD AND MATERIALS

An SSP-3 solid-state photometer along with filters closely matching the Johnson B, V, R and I system were used in the collection of all photometric data. The photometer has an aperture of 1.0 mm which yields a field of view of 54 arc-seconds when used with the 36 cm f/11 telescope at Texas A&M University Observatory. A S1087-01 silicon PIN-

TABLE 1—Coordinates (2000.0) and magnitudes of the comparison stars used in the study of NGC 7027. All star magnitudes are from Iriarte et al. (1965).

Star Characteristic	62 ξ-Cyg	61 -Cyg A	ν -Cyg
Right Ascension	$21^{h}\,04^{m}.9$	$21^{h}\,06^{m}.9$	$20^{h}\,57^{m}.2$
Declination	$+43^{\circ}\,55^{m}.7$	$+38^{\circ}\,45^{m}.0$	$+41^{\circ}\,10^{m}.0$
Spectral Class	K5	K5	A0
B-mag	5.35	6.42	—
V-mag	3.70	5.25	3.94
R-mag	2.49	4.23	—
I-mag	1.59	3.57	—

photodiode detector manufactured by Hamamatsu Corporation serves as the detector for this instrument. This detector is quite sensitive in the wavelength range 0.4-1.0 microns with a peak sensitivity near 0.94 microns. More information on the instrument and filters can be found elsewhere (Optec, 1988).

Texas A&M University Observatory is located at (30.6°N, 96.3°W) and is at an elevation of 100 m. It is equipped with a 36 cm f/11 Schmidt-Cassegrain Telescope which is mounted on a Byers Mount. The good mounting was necessary for the long integration times used in this study.

The B, V, R and I measurements of NGC 7027 were usually made first which was then followed by B, V, R and I measurements of the comparison star. Due to the faintness of NGC 7027, the integration time was 200 ss (twenty-10 s integrations) for the B filter and 100 ss (ten-10 s integrations) for the V, R and I filters. The integration time for all comparison and check star measurements was 30 ss (three-10 s integrations). For each measurement, several sky brightness readings made near the object were recorded both before and after the object readings. The average sky brightness (which included the instrument offset) was subtracted from the object reading yielding the brightness of just the object. In all cases, the signals included an instrument offset. The instrument offset was not measured during the study of NGC 7027 and thus, individual sky brightness measurements can not be reported. The typical sky brightness (counts per 10 ss) are estimated to be 2, 9, 5 and 14 for the B, V, R and I filters respectively while the mean values for NGC 7027 are 17, 51, 57 and 54 for the B, V, R and I filters.

The variation in the instrument offset was measured several times by the author to be 0.5 counts per 10 ss on the same scale used in measuring NGC 7027. The variation (V) was calculated from

$$V = \frac{2\sigma_O}{\sqrt{N}} \qquad (1)$$

where σ_o is the standard deviation of the offset measurements and N is the number of 10 s integrations made (usually 10). Therefore, the ratio of the signal of NGC 7027 to the offset variation ranged from 30 in the B filter up to 90 in the R filter.

The comparison star used for all measurements was 62 ξ -Cyg while 61-Cyg A and v-Cyg were check stars for some of the measurements. The coordinates and magnitudes of all three stars are listed in Table 1. The comparison star, 62 ξ -Cyg was selected because it was close to NGC 7027 and its B, V, R and I magnitudes are well known (Iriarte et al., 1965; Johnson et al. 1966). The check star, 61-Cyg A, was selected because its B, V, R and I magnitudes are well known and it is also listed as a reference star in the Nautical Almanac (1992). The measured V, R and I magnitudes of 61-Cyg A and the V magnitude

TABLE 2.—Photometric measurements of NGC 7027.

Date (1993)	Measured Magnitude B	V	R	I	Δ Air Mass
Sept. 28.26	9.93	8.87	8.24	8.12	−0.09
Sept. 29.07	9.96	8.89	8.21	8.14	+0.01
Sept. 29.11	9.82	8.85	8.25	8.11	−0.02
Sept. 30.21	9.85	8.87	8.23	8.18	+0.02
Sept. 30.25	9.81	8.87	8.24	8.21	+0.05
Oct. 1.09	9.84	8.92	8.24	8.21	0.00
Oct. 2.14	9.92	8.91	8.22	8.19	−0.02
Oct. 2.18	9.86	8.87	8.25	8.23	−0.04
Oct. 2.20	9.93	8.91	8.25	8.23	−0.04
Oct. 2.23	9.79	8.89	8.24	8.25	+0.03
Oct. 9.11	9.93	8.95	8.22	8.26	−0.01
Oct. 9.14	9.88	8.94	8.23	8.23	+0.01
Oct. 9.16	9.91	8.90	8.23	8.24	+0.01
Oct. 10.17	9.93	8.85	8.24	8.22	+0.02
Oct. 10.20	9.84	8.95	8.24	8.33	+0.04
Oct. 11.15	9.85	8.85	8.26	8.19	−0.03
Oct. 11.18	9.82	8.86	8.25	8.21	+0.02
Average	9.87	8.89	8.24	8.21	—
σ	0.05	0.03	0.01	0.05	—

of v-Cyg are consistent with the values in table 1 to within 0.02 magnitudes; there is a slightly larger discrepancy of .066 magnitudes in the B magnitude of 61-Cyg A.

RESULTS

The measurements of NGC 7027 are summarized in Table 2. The last column in this table, Δ Air Mass, is the air mass of 62 ξ -Cyg subtracted from the air mass of NGC 7027. All measurements are corrected for atmospheric extinction. In some cases, the extinction coefficients were measured, however in other cases, no extinction coefficients were measured; in these cases, extinction coefficients of 0.40, 0.25, 0.20 and 0.15 magnitudes per air mass were used for the B, V, R and I filter measurements respectively; these are averages of measurements made at Texas A&M University Observatory. This assumption introduces a negligible error because the difference in air mass between the comparison star and NGC 7027 was always below 0.1 air masses.

The extinction coefficients were determined from one of two methods. In the first method, the magnitudes of two stars of known brightness, but at different elevations were measured. The magnitude of the star at the lower altitude or higher air mass (star B) was measured using the other star (star A) as a reference. The difference between the measured and actual magnitude (Δ magnitude) of star B was determined; this quantity was divided by the difference of the air mass of stars A and B (Δ Air mass) in determining the extinction coefficient. This procedure was carried out for all four filters. In the second method used in determining extinction coefficients, the author plotted the logarithm of the counts per 10 s of a single star versus the air mass. The slope was then multiplied by 2.5 yielding the extinction coefficient. All measurements were restricted to less than three air masses.

Average magnitudes of +9.87 ± 0.05 (B); +8.89 ± 0.01 (V); +8.24 ± 0.01 (R) and +8.21 ± 0.02 (I) for NGC 7027 are calculated from the average of the values in Table 2. The uncertainties (U) of the V, R and I magnitudes are calculated from:

$$U = \sqrt{(\sigma/\sqrt{N})^2 + s^2} \tag{2}$$

where σ is the standard deviation of the measurements in Table 2, N is the number of measurements (17), s is the uncertainty in the star magnitude which is 0.01 magnitude in the V, R and I filters. The uncertainty of the B magnitude is taken to be 0.05 magnitude due to the inconsistency with the check star.

Discussion

The B-V, V-R and R-I magnitudes for NGC 7027 have been measured as +0.98, +0.65 and +0.03. These values indicate that NGC 7027 has a reddish instead of a bluish color as seen from the Earth. The color is undoubtedly effected by interstellar extinction (Kaler et al. 1976) and so the colors measured in this paper are probably not the actual colors of NGC 7027. Nevertheless, the actual color can be calculated using the correct interstellar extinction coefficients. The wide range of reported magnitudes for NGC 7027 could be due to a variability in the brightness or the colors of this nebula. Therefore, it is concluded that future photometric measurements of this nebula be made to check for variability.

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RECENT LANDSLIDING OF UPPER CRETACEOUS ROCKS NEAR DALLAS, TEXAS

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Abstract.—For more than 40 years the area between the towns of Forney and Terrell in northeast Texas has been relatively stable geologically, even though the tract is underlain by argillaceous strata (marl and shale) that form thick expansive soils. During the last few years, small-scale landslides have remodeled the land surface, collapsed some wooden structures, severed sewer and water pipes, snapped telephone cables, and resulted in leaning power poles and fence posts. The movement has occurred along the outcrop trend of the 145-m-thick Upper Cretaceous Marlbrook/Neylandville marl sequence. These marls, which contain a high percentage of montmorillonite clay and thin (0.5-1 cm) bentonite beds, are well known in the region for forming irregular, hummocky topography. One of the principal causes of downslope movement since late 1990 is the saturation of soil and bedrock on sensitive slopes by unusually heavy local rainfall. Total precipitation in the Dallas area since 1989 ranged from 15.9 cm to 50.4 cm above normal (85.6 cm) according to the U.S. Weather Service. Higher than normal rainfall, coupled with gravitational forces, rendered even low- to moderate-slopes in the area unstable.

The general term "landslide" refers to a number of specific topographic features and earth processes that involve rapid to moderately rapid (approximately 0.3 m per year or more) downslope movement of rock and soil as a unit in response to gravitational body forces (American Geological Institute, 1972). Legget (1973) remarked that the presence of numerous landslides, both large and small, new and old, throughout most of the world points to their importance in the normal geological cycle. Landslides are significant geologic hazards that occur in nearly every part of the United States. Financial losses resulting from this type of ground failure are significant. In terms of 1990 dollars, the cost of this type of hazard was two billion (Nuhfer, 1993). These costs may be either direct or indirect. Direct costs are related to losses incurred in actual damages to structures or property (Hays, 1981). The threat or development of landslides may also result in indirect costs such as the reduction of real estate taxes on devaluated property or the loss of agricultural and industrial productivity (Hays, 1981).

The study area, about 48 km east of Dallas, is within the Black Prairie physiographic province in northeast Texas (Fig. 1). This region is underlain mostly by argillaceous limestone and marl that weather to a black waxy soil designated as "clayey blackland" by the Soil Conservation Service (Pringle, 1977). A 8.1 ha tract between the towns of Forney and Terrell in northern Kaufman County, Texas (Fig. 2) has

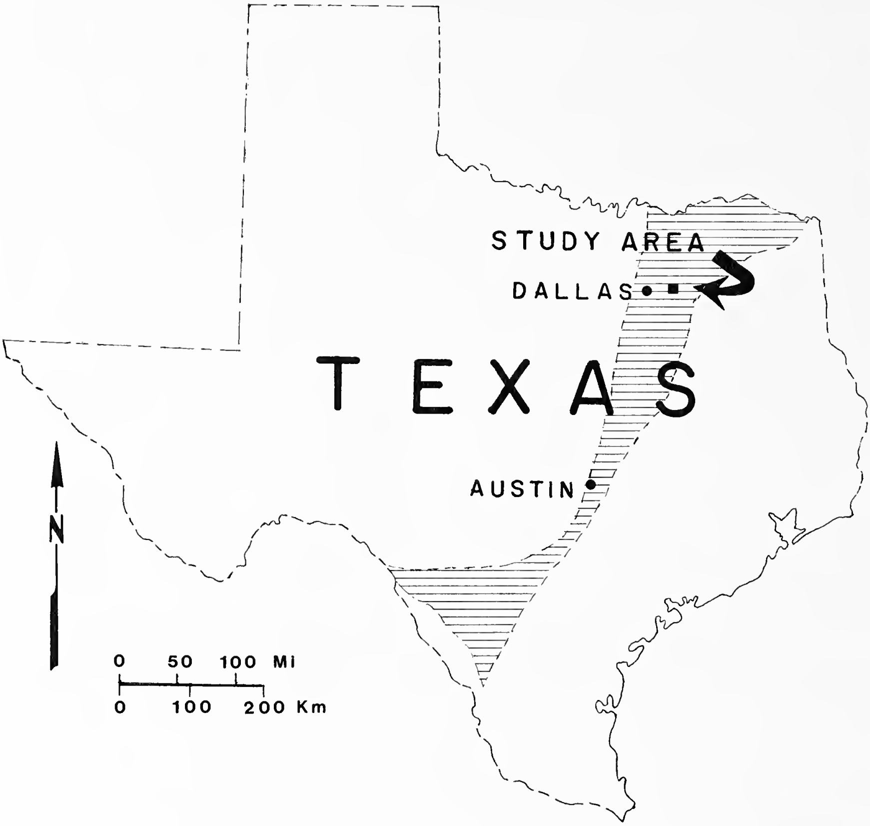

FIGURE 1. Map showing general location of study area and Black Prairie Physiographic Province (shaded area). Black Prairie region modified from Hill (1901, plate 1).

been examined in detail. This parcel, which is underlain by the Ferris-Heiden complex and Burleson clay soils, supports a variety of grasses including bluestem (*Andropogon furcatus*), grama grass (*Bouteloua* sp.), indian grass (*Sorghastrum* sp.), and switchgrass (*Panicum virgatum*) and a few trees (Pringle, 1977, sheet 25). Scattered hackberry (*Celtis occidentalis*), locust (*Robina pseudoacacia*), and mesquite (*Prosopis juliflora*) trees are also present. These soils are classified as fine, montmorillonitic, thermic vertisol (Pringle, 1977). The solum associated with the Ferris clay ranges from 76 to 165 cm thick; also, wide, deep (>51 cm) cracks are common in the upper part (Pringle, 1977). The site is a short distance north of U.S. Highway 80 near the small community of Lawrence. The tract lies approximately 152 m from the southward-flowing Terry Creek. In the study area, the estimated stream gradient is nearly 3.7 m/km. and the slope of the adjacent land surface is less than a 5% grade.

Local topography is irregular and consists of low rolling, grass-

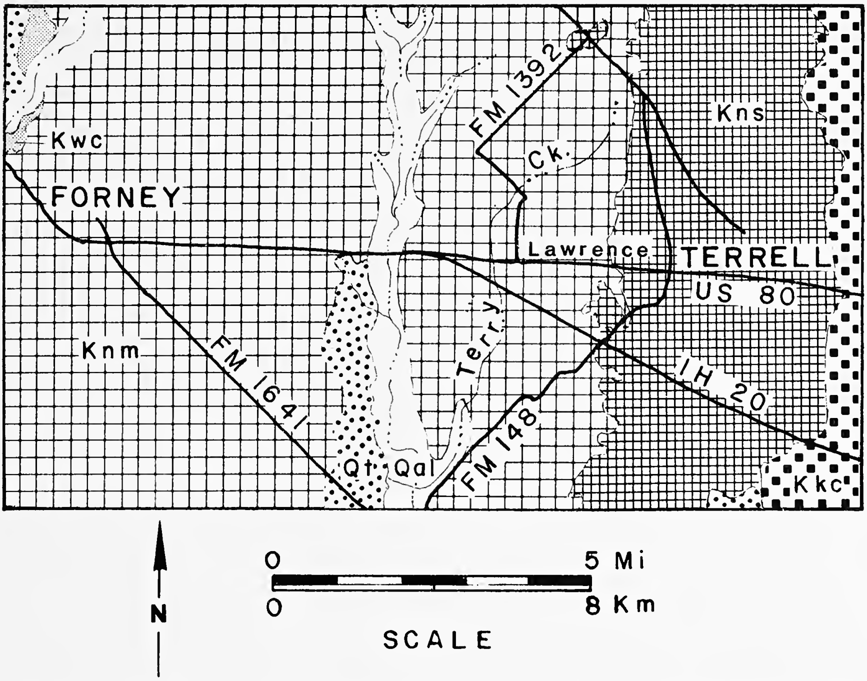

FIGURE 2. Generalized geologic map of study area. From oldest to youngest, these formations include Upper Cretaceous Wolfe City (Kwc), Marlbrook/Neylandville undivided (Knm), Nacatoch (Kns), Kemp/Corsicana undivided (Kkc), Pleistocene fluviatile deposits (Qt), and Holocene alluvium (Qal). Map modified from Barnes (1988).

covered hills separated by a series of narrow, elongate furrows. Elevation generally ranges from 137 to about 163 m above sea level (U.S.G.S., 1962). Most of the land is pasture with a small part utilized as residential/light industrial property. The land, which was farmed and grazed by cattle during the 1950's and 1960's, has been idle for the last 25 years. Since 1967, it has been utilized as a natural plant preserve by the Soil Conservation Service.

STRATIGRAPHY

The study area is underlain by marine Upper Cretaceous rocks designated as undivided Marlbrook and Neylandville formations (Barnes, 1988). These formations, which are lithically similar throughout the Dallas area, consist of silty, gray calcareous clay or marl (Barnes, 1988). Faunal elements within this stratigraphic interval (upper part) include abundant *Exogyra cancellata*, a large oyster with a distinctly cancellated shell (Adkins, 1978). Barnes (1988) reported that the Neylandville Formation commonly produces irregular topography in northeast Texas. The age of these rocks ranges from late Campanian

SERIES	GROUP	FORMATION
UPPER CRETACEOUS Gulfian	Navarro	Kemp Clay/Corsicana Marl
		Nacatoch Sand
		Neylandville Marl
	Taylor	Marlbrook Marl
		Wolfe City Sand

Figure 3. Upper Cretaceous rocks exposed in the study area.

to early Maastrichtian. The general stratigraphic relations in the study area are given in Figure 3.

Northward, the marl sequence is subdivided into the subjacent 107-m Marlbrook and superjacent 38-m Neylandville formations (Barnes, 1988). The marl interval is underlain and overlain by the Wolfe City and Nacatoch sandstones, respectively (Figs. 2 and 3).

Beall (1964) studied the Taylor Group in east-central Texas, and reported that the Marlbrook and Neylandville formations could not be differentiated. He observed (Beall, 1964) that the Marlbrook Formation (upper Taylor Marl) was composed mostly of montmorillonite with different amounts of calcite fragments, quartz silt, glauconite, pyrite, and locally high amounts of phosphatic material. Dawson et al., (1985) reported the presence of thin (up to 1 cm) bentonite beds in the lower Marlbrook (upper Taylor marl) in northeast Texas. XRD analyses of the beds indicated that these rocks consist mostly of smectite.

Structural Setting

Strata in the area generally trend north-northeast and dip less than one degree south-southeast. Although elements of the Mexia-Talco

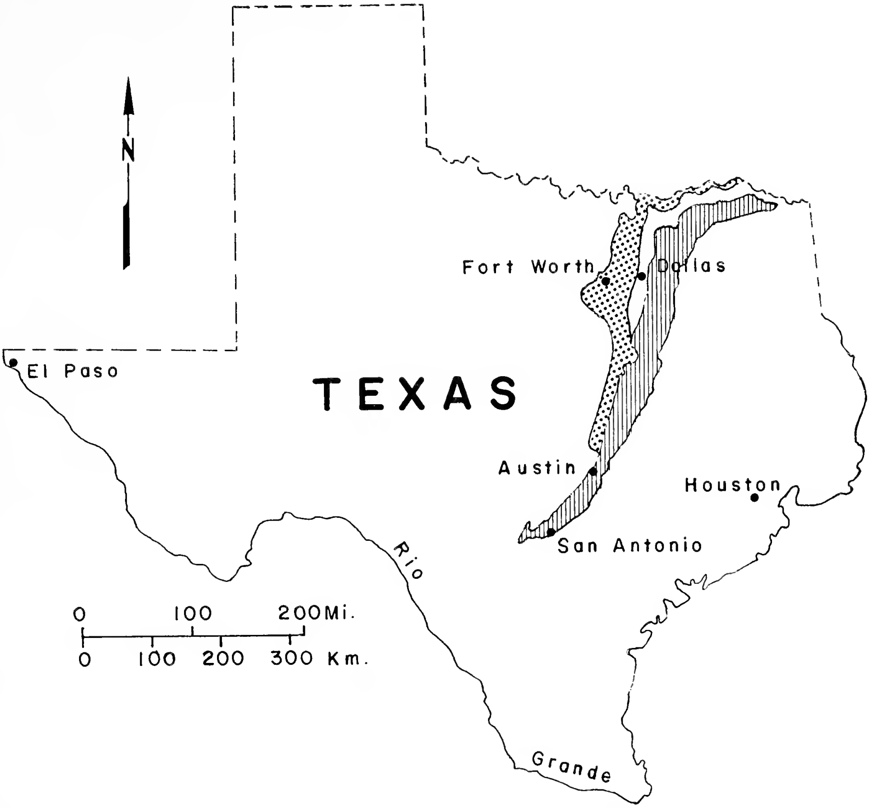

FIGURE 4. Map of Texas showing areas of high (ruled pattern) and moderate (dot pattern) landslide susceptibility (modified from Radbruch-Hall et al., 1981).

fault system, a zone of inactive *en echelon* normal faults, occur about 15 km east of the study area (Barnes, 1988), the area of investigation is tectonically stable. This part of Texas lies within a low-risk seismic zone, *i.e.* a zone where no damage is expected from seismic activity (Algermissen, 1969). The nearest activity was in southwest Hunt County (epicenter about 72 km northeast) during 1969 and was too minor to have an assigned intensity value (Reagor et al., 1988). There are no active quarries or blasting operations in the vicinity that could result in significant ground motion.

EVIDENCE OF MASS WASTING

The study area is within an outcrop belt with moderate landslide activity. This belt, at places 56 km wide, extends north-northeastward from San Antonio nearly to Texarkana, a distance of 680 km (Fig. 4). The region is characterized as an area of low landslide incidence (less than 1.5% of area involved) but high landslide susceptibility

FIGURE 5. Northwest aerial view of water-filled, handdlebar-shaped crack in land surface (arrows, lower left). Terry Creek flows diagonally across the photo (Courtesy of D. Wathen).

(Radbruch-Hall et al., 1981). However, the area has been relatively stable for more than 40 years (D. Wathen, 1993, pers. comm.). In late 1990, significant changes in the land surface began to occur and continued to mid-1993. Numerous, water-filled cracks formed on the property and produced a distinctly hummocky surface. Bolt et al., (1975) remarked that fractures which form and widen during an interval of time usually forecast a future landslide. They also observed (Bolt et al., 1975) that rumpled topography characterizes the movement of some slide masses. Low hills have collapsed at some places on the property. A preliminary pocket transit survey conducted by the author, when compared with a 1962 topographic survey (USGS, 1962), suggested probable changes in elevation of less than a meter. Adjacent to the northwest part of the property, a long (24 m), handlebar-shaped crack developed in 1993. Initially, this water-filled ditch was approximately 1-2 m wide and up a meter deep (Fig. 5). Currently, the crack is mostly closed, but is still visible from ground level.

Small ponds on the lower slope of the tract began to fill rapidly as water rose from below and brought exotic rocks and pebbles (concertion fragments and terrace gravel?) to the surface. The soil became waterlogged and supported the growth of abundant green algae. The ground was so saturated that it made walking difficult.

The landowner, who resides in a trailer home on the property, reported several "jolts" that were strong enough to displace books and

TABLE 1. Annual precipitation recorded from 1986 to 1992 at Dallas/Fort Worth International Airport S(1, National Weather Service, 1993) compared with total rainfall recorded near the area of investigation from January, 1989 to October, 1993 (2, Joel Wardlaw, 1993, pers. comm.)

Year	*Total Rainfall (centimeters)*	
	1	*2*
1986	82.42	—
1987	69.22	—
1988	63.60	—
1989	1001.47	106.05
1990	114.99	135.13
1991	135.99	162.13
1992	107.16	131.32
1993	83.39	*56.26

*January-September

dishes from their resting places and tilt the trailer into newly formed surface cracks (Wathen, 1993, pers. comm.). These vibrations probably occurred as the surface layers were displaced along the slip planes of individual landslides. An old (more than 100 years), two-story wooden barn about 46 m from the trailer collapsed as the soil and bedrock shifted downslope. Also, nearby power-line poles tilted in the direction of Terry Creek. In the northern part of Terrell, about 3 km to the east, numerous water and sewer lines as well as telephone cables were ruptured and the foundations and roofs of several homes were broken as the ground shifted (Wathen, 1993, pers. comm.). According to Joel Wardlaw (1993, pers. comm.), these are common problems related to expansive soils in the area.

CAUSE OF DOWNSLOPE MOVEMENT

Above average rainfall from 1989 to 1992 is probably the major factor contributing to downslope movement of soil and bedrock in the local area. The annual rainfall at Dallas/Fort Worth International Airport (Table 1) for the last three years ranged from 25% to 59% above normal. Based on the average precipitation recorded in this vicinity from 1951 to 1980, normal rainfall for the area is 85.6 cm (National Weather Service, 1993). Although the recording weather station is about 72 km west of the study area, the data probably reflect the general precipitation in the region. Joel Wardlaw, a technician with the Soil Conservation Service in Kaufman, Texas, unofficially recorded the total rainfall at his home from 1989 to late 1993. His residence is about 1.6 km from the study area; the precipitation recorded there is significantly higher than total rainfall recorded officially at D/FW Airport for the last four years. These data are given in Table 1.

Dalles et al. (1993) stated that intervals of heavy rainfall can initiate movement of unstable slopes if the right geological conditions exist. This is especially true when montmorillonite, a clay mineral with the chemical formula $(Mg, Ca)0 \cdot A1_20_3 \cdot 5Si0_2 \cdot nH_20$ (Rogers and Kerr, 1942), makes up the bulk of the rock body. Blatt (1994) pointed out that this mineral is characterized by high liquid and plasticity limits and a low shrinkage limit (Attenberg limits), all factors that contribute to ground failure. When compared with illite and kaolinite, two other common hydrous aluminosilicates, montmorillonite exhibits a major volume change in the presence of water. Montgomery (1992) reported that the mineral readily absorbs water and can hold twenty times its weight in liquid and form a weak gel. Legget and Hatheway (1988) and Montgomery (1992) also reported that abundant rainfall can rapidly add weight, decrease friction, and increase the pore pressure of clay-rich soils. Cargo and Mallory (19977) observed that most examples of mass wasting have resulted from the addition of water into the ground to the point that the strength of the material is reduced beyond its ability to withstand the force of gravity.

Landsliding in water-saturated argillaceous strata is not unique to Texas; it occurs in other parts of the world. For example, Legget (1973) reported similar but larger landsliding near Handlova in central Czechoslovakia. There, excessive rainfall percolating through argillaceous rock unbalanced the delicate groundwater condition that was present beneath the sloping ground. As a result of this condition, a large mass of soil and rock debris began moving toward the town in late 1960 but was brought under control by the emplacement of tunnels and pipes to drain the slide mass (Legget, 1973).

Conclusions

Based on field observations, landslides in the study area can be classified as lateral (earth) spreads where extension of the bedrock and soil have resulted from "liquefaction" or plastic flow of subjacent material (Hays, 1981). Precipitation from locally heavy rains in the Forney-Terrell vicinity from 1989 to 1992 has invaded soil and argillaceous bedrock of the Marlbrook/Neylandville formations causing the local water table to rise near ground level. The saturated mass became unstable and moved downslope in response to gravitational forces. The disturbed areas are characterized by the 1) opening and widening of surface cracks, 2) collapsing of locally high areas, and 3) shifting of surface layers downslope. Control measures should include slope reduction and drainage of the rock mass by utilizing narrow ditches and/or closely spaced pipes; however, this type of remediation would be expensive and probably not be cost effective in this rural setting. Developers in this area should consider lime stabilization of the soil or a ponding (preswelling) technique before pouring a slab foundation.

Acknowledgments

I thank Ms. Dorothy Wathen, a native American woman who is keenly aware of subtle changes in her environment, for access to her property near Lawrence, Texas and for a photo used in this paper. I am indebted to Mr. Joel Wardlaw, Soil Conservation Service, Kaufman, Texas for providing technical information concerning the study area and rainfall data from his residence. Thanks are also extended to personnel at the U.S. Weather Service, Fort Worth, for weather data from the D/FW Airport Station. I am grateful to Dr. William C. Dawson, Texaco EPTD, Houston, Texas for critically reading an early version of the manuscript.

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A MODIFIED FLOW TANK DESIGN THAT FACILITATES CHOICES OF CURRENT VELOCITY (RIFFLE VERSUS POOL)

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Abstract.—Artificial streams are an effective means of studying the behavior of aquatic insects because the simulated environment can be controlled and manipulated easily. The described modifications to the design of Herrmann et al. (1992) present several advantages over previous designs. The modified flow tank allows for choice of current velocity as well as substrate, and provides a larger area for study. The design is inexpensive ($650.00, 1993), easy to construct, and provides homogeneous currents throughout riffle or pool areas.

Field experiments involving aquatic taxa have been conducted directly in streams to maintain the environmental conditions required for the survival of the organisms. In general, organisms were placed in screen cages which were partially or completely submerged. Unfortunately, problems such as flooding or human intervention contributed to the loss of organisms or experimental replicates (Sudia, 1951). Additional problems with the screen cages included the inability to control abiotic factors such as temperature, pH, and oxygen content. Finally, current velocity surrounding screen cages was inconsistent due to resistance of the screen decreasing water velocity (Sudia, 1951). Laboratory flow tanks were developed to eliminate such complications. Artificial streams provide a practical means of controlling many abiotic factors while varying factors of interest.

Artificial streams provide an opportunity to study lotic organisms in a controlled environment where all but characteristics of interest are held constant (Lauff and Cummins, 1964). In general, flow tanks are ideal for behavioral studies evaluating intra- and interspecific interactions such as competition and predation (Feltmate, 1987; Williams, 1987; Fuller and Rand, 1990). More specifically, studies of habitat selection with flow tanks (Herrmann, 1992; Herrmann et al., 1993) have proven effective because abiotic factors and substrate are easily modified to correspond to particular experimental designs.

Early flow tanks were large, complex, expensive to build, and difficult to manipulate (Sudia, 1951). Subsequent designs were specific for experiments evaluating the behavior of particular species (Bainbridge and Brown, 1958; Vogel and Feder, 1966; Svoboda, 1970), and often were too specialized for general ecological studies. Flow tanks were designed later that were less complex, economical, and easy to construct (Vogel and LaBarbera, 1978; Mackay, 1981; Lamberti and Steinman, 1993). Recently, Herrmann et al. (1992) designed a flow tank with notable advantages over previous designs. Their flow tank

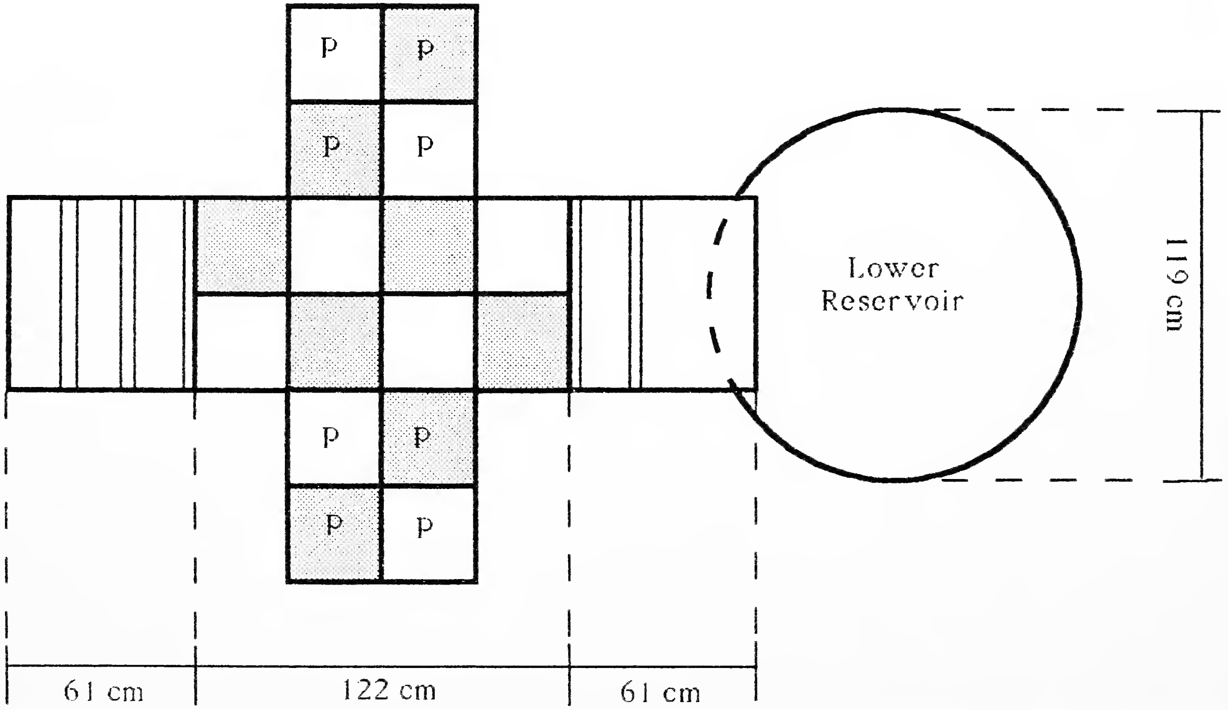

FIGURE 1. Diagrammatic representation of the artificial stream. Quadrats in pool area are represented by a "P" whereas riffle areas are unmarked. Alternating configuration of substrate is indicated by shaded vs. non-shaded areas.

required little floor space, produced accurate current velocities, simulated a riffle environment, and produced currents which were consistent spatially and temporally throughout the tank (Herrmann et al., 1992). Their design was inexpensive and easy to build; one person could construct a tank in two days. Although this design facilitates substrate choice, it does not permit a choice of current velocites (e.g., riffle vs. pool).

Modifications of the flow tank design to allow a choice of velocity are presented hereafter. In particular, modifications allow organisms to choose between a riffle and pool habitat, with substrate contrasts offered in each habitat (fig. 1).

MATERIALS AND METHODS

In general, the flow tank design was modified from that of Herrmann et al. (1992). The flow tank comprises four main sections: riffle area, pool area, water supply, and water pump. The riffle area is a long rectangular trough supported by four posts, whereas the pool area is divided into two square troughs each supported by three posts. The riffle and pool areas together form the upper reservoir. A cylindrical tin tank contains the water supply and submersible pump (lower reservoir) which circulates the water throughout the entire flow tank. Water is lifted through the plumbing to the emptying chamber in the upper reservoir where it flows via gravitation toward the lower reservoir, falls into the tin tank, and is recycled.

Upper reservoir.—The riffle area of the upper reservoir was constructed according to Herrmann et al. (1992). Pool areas were constructed from 1.9 cm (three-fourths in) plywood. Galvanized nails and silicone were used to secure the walls to each base plate. Each pool section measured 61 cm by 61 cm (2 Ft by 2 Ft), so that the total pool area was 244 cm by 61 cm (8 Ft by 2 Ft, fig. 1). The entire upper reservoir was then covered with a single sheet of 6 mm plastic, to prevent water leakage. Total riffle area was equal to the total pool area available for experimentation. Each pool section was divided into four qudrats using 2.5 cm (1 in) corner molding as partitions. The riffle area was bounded by an upper and a lower mesh screen to keep organisms within the study area. A single weir was used in the upper reservoir to control water turbulence within the emptying chamber. Water levels were controlled by the lower mesh screen and lower weir, whereas water velocity was controlled by the pump and gate valve. The lower weir can be removed to achieve maximum current velocity in the riffle area. Water depth (with the lower weir in place) remains constant at approximately 20.3 cm; however, water depth can be changed by adjusting current velocity (via the gate valve) and weir placement.

Lower reservoir.—The lower reservoir comprises a cylindrical galvanized tin tank, a submersible 0.5 Hp sewage pump (Goulds model 3887, Seneca Falls, New York), and PVC plumbing for transport of water to the upper reservoir. The diameter of the tin tank is 119 cm, with a volumetric capacity of 2.73 m^3. Water temperature may increase initially due to electrical resistance within the pump; however, maximum temperatures measured were 29°C (Herrmann et al., 1992). A gate valve was fitted between PVC piping to control current velocities. No directional flow of water was detected in pool areas. The gate valve can be manipulated to produce a variety of current velocities in the riffle area between 0 and 45.45 cm/second.

DISCUSSION

The modified flow tank presented herein not only contains all the advantages of the previous design (Herrmann et al., 1992), but offers a larger study area and permits selection of current velocities. Modifications to the flow tank were inexpensive (approximately $150.00); total cost of a modified flow tank equals $650.00. Construction of a modified flow tank by a single individual can be accomplished in three days.

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KHAYYAM, AL-BIRUNI, GAUSS, ARCHIMEDES, AND QUARTIC EQUATIONS

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ABSTRACT.—Omar Khayyam's solution of cubic equations which employs the parabola $y = x^2$ and circles, is applied to construction of some geometric configurations.

INTRODUCTION

The interest in Archmedes' problem was revived by Persian mathematicians of the ninth centruy (Smith, 1958). The problem amounted to solving the equation $x^3 + a^2b = cx^2$. Abu Ja'far Al-Khazen (c 960), a native of Khorasan, Persian, as Omar Khayyam tells, solved the equation by the aid of conic sections (Smith, 1958). So Omar Khayyam (1044-1123) became interested in classifying and solving cubic equations by the aid of conic sections (Mossaheb, 1960). An extension and simplification of Omar's work was presented by the late Dr. M. Hachtroudi*, using only circles and the parabola $y = x^2$.

In this article we present the work of Hachtroudi and apply it to a problem of Khayyam. Then the techniques of Al-Birooni (c 1000) and C. F. Gauus (c 1800) are used for obtaining equations related to some geometric constructions.

The elegant radical solutions of cubic and quartic equations by Nicolo Tartaglia (c, 1543) and L. Ferrari (c, 1545) can not be used in geometric constructions.

Nowadays, with modern technology, $y = x^2$ can be accurately constructed. The Hachtroudi's simplification of Khayyam can easily be applied to many geometric problems.

Theorem: The four points of intersection of two parabolas whose axes are perpendicular are on a circle.

Proof: For convenience, without loss of generality, parabolas are chosen:

$$y^2 = 4p(x - a),\ x^2 = 4q(y - b). \tag{1}$$

It is clear that the axes of these parabolas are perpendicular to one another. Now if these equations are added, the result is

$$x^2 + y^2 - 4px - 4qy + 4ap + 4bq = 0 \tag{2}$$

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*The late Dr. Mohsen Hachtroudi was professor of mathematics at the University of Teheran. He received his degree of Dacteur d'édtat under the direction of Eli Cartan in 1936.

which is a circle with center $(2p, 2q)$. This proves the theorem. Here the complex points of intersection have also been considered. Omar proved this theorem synthetically.

SOLUTION OF CUBIC EQUATIONS

Any third degree equation can be written as

$$x^3 + lx^2 + mx + n = 0. \tag{3}$$

If solution of a fourth degree equation is discussed such as

$$z^4 + az^3 + bz^2 + cz + d = 0, \tag{4}$$

then (3) will be a special case of (4). So, consider

$$x^4 + lx^3 + mx^2 + nx = 0. \tag{5}$$

The root $x = 0$ is ignored, and the roots of (3) can be determined.

Now proceed with the solution of (4). If the change of variable $z = x - (a/4)$ is chosen, the equation (4) changes to the form

$$x^4 + Ax^2 + Bx + C = 0. \tag{6}$$

Choose $y = x^2$. Then determining the roots of (6) is the same as solving the system of equations

$$\begin{cases} x^2 = y \\ y^2 + Ay + Bx + C = 0 \end{cases} \tag{7}$$

for x.

It is easily seen that the equations of (7) are the equations of two parabolas whose axes are perpendicular to one another. The solution of (7) is obtained by the system

$$\begin{cases} x^2 = y \\ x^2 + y^2 + (A - 1)y + Bx + C = 0. \end{cases} \tag{8}$$

The advantage of (8) is that the parabola $y = x^2$ can be drawn accurately on a sheet of scaled paper. Then a circle of center

$$\left(\frac{-B}{2}, \frac{1-A}{2} \right) \tag{9}$$

and radius

$$\frac{\sqrt{A^2 + B^2 - 4AC - 2A + 1}}{2} \tag{10}$$

can be drawn on a sheet of transparent paper. If the circle is superimposed on the parabola and the roots are read on the x-axis (Fig. 1).

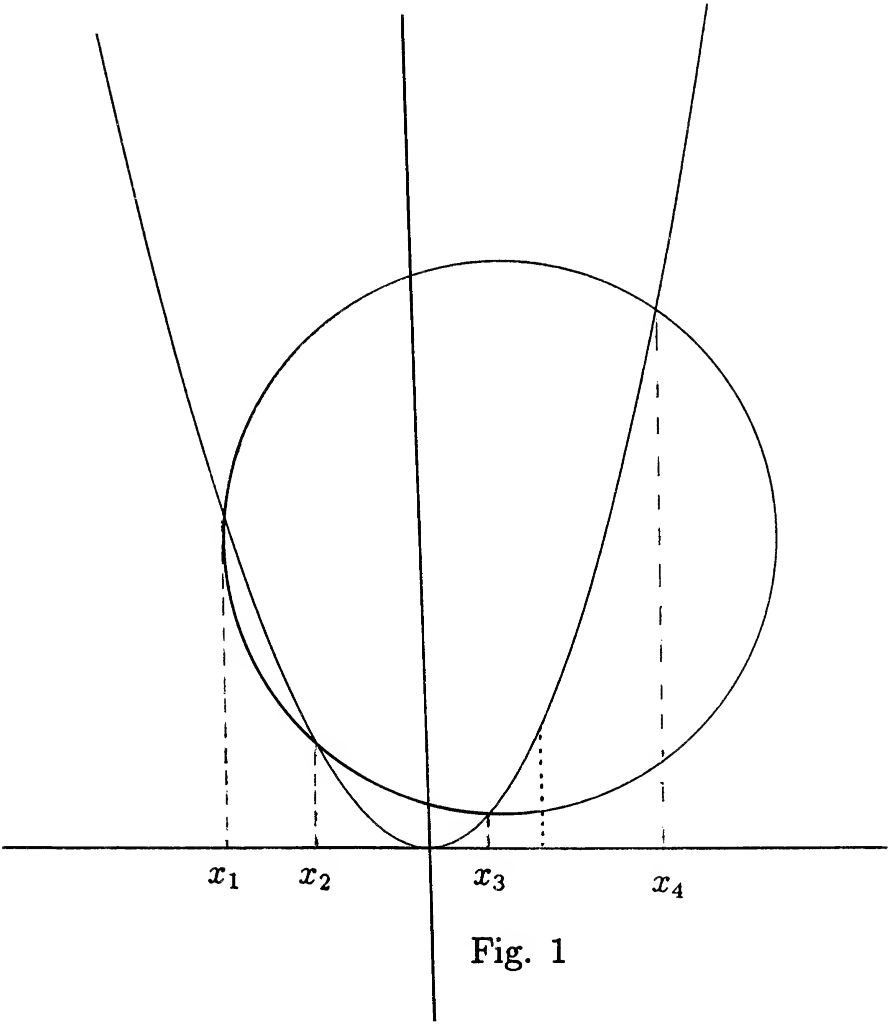

Fig. 1

KHAYYAM'S PROBLEM

An interesting problem started Omar Khayyam on employing conic sections in solving cubic and quartic equations. It is desired to divide the one fourth *AB* of the circle *ABCD* by a point *R* into two parts such that, if *RH* is drawn perpendicular to the diameter *BD*, (11) is obtained

$$\frac{AE}{RH} = \frac{EH}{HB} \tag{11}$$

where *E* is the center of the circle (Fig. 2).

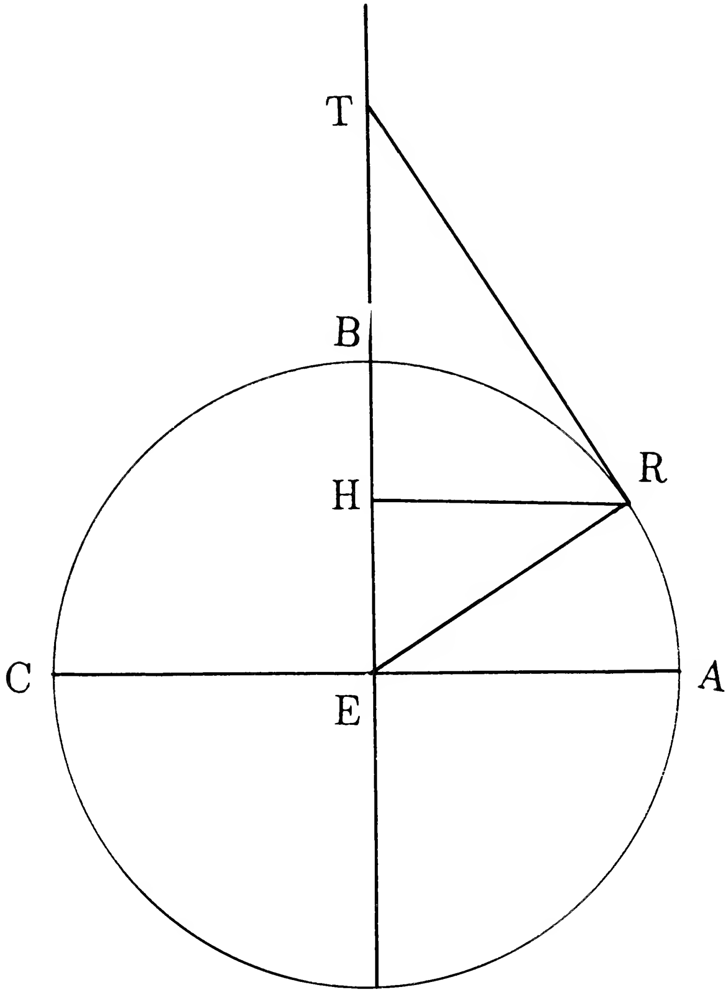

Fig. 2

Khayyam's solution is quite involved with a long discussion of cubic equations, a simpler solution is given:

Suppose the problem is solved and R is the desired point. ER is drawn. The tangent line at R intersects EB at T. Then in the right triangle ERT is

$$ER^2 = (EH)\,(ET) \tag{12}$$

and

$$RH^2 = (EH)(HT). \tag{13}$$

Let $EH = x$, $ER = 1$, $ET = t$. Then from (12) and (13) is obtained

$$1 = xt \tag{14}$$

and

$$RH = \sqrt{x(\mathrm{t} - x)}. \tag{15}$$

Substituting (14) and (15) in (11),

$$\frac{1}{\sqrt{x(t-x)}} = \frac{x}{1-x}. \tag{16}$$

So from (16) is obtained

$$x^4 - 2x + 1 = 0 \tag{17}$$

It is observed that *1* is a root of (17), but instead of factoring it is treated with Omar's technique.

Choose $y = x^2$. The with (17)

$$\begin{cases} y^2 - 2x + 1 = 0 \\ x^2 - y = 0. \end{cases} \tag{18}$$

From this set of equations the circle

$$(x-1)^2 + \left(y \;\; \frac{1}{2}\right) = \frac{1}{4} \tag{19}$$

is obtained

Thus, the circle of center (1, 1/2) and radius 1/2 intersect the parabola $y = x^2$ at two points (Fig. 3). Note that since $x < 1$, the root $x = 1$ is not used in obtaining R.

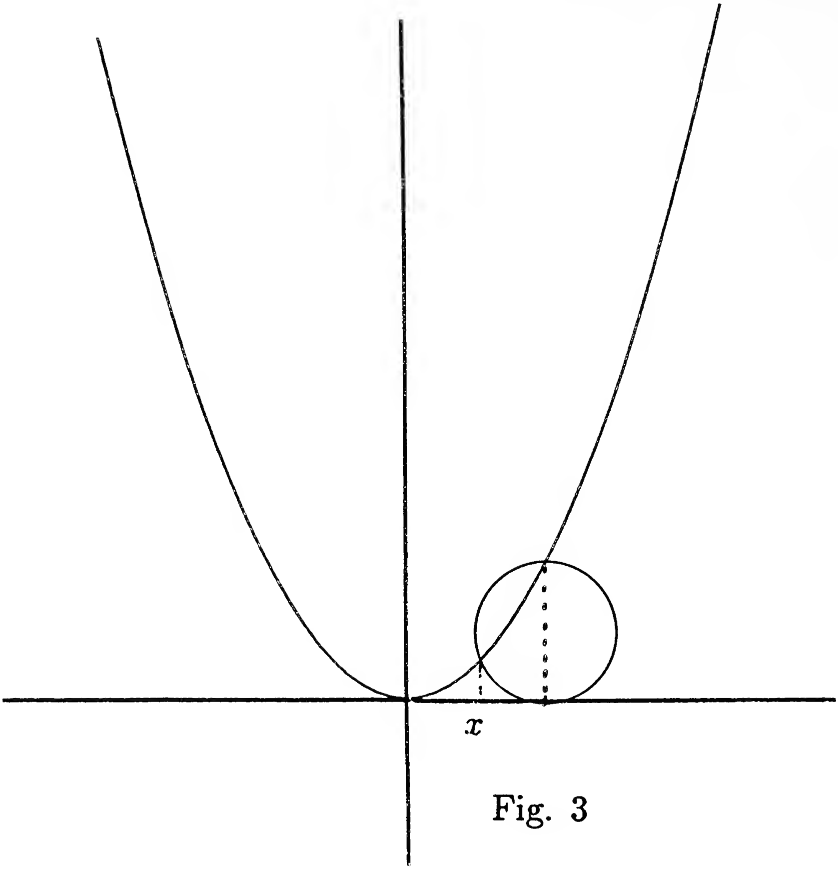

Fig. 3

Regular Nonagons

If a circle is divided into nine equal arcs, the central angle corresponding to each arc is 40° (Fig. 4).

Al-Biruni first chose $AB = 2 \sin 20°$, for the unknown. Observing that

$$\sin 60° = 3 \sin 20° - 4 \sin^3 20°, \tag{20}$$

and setting $AB = x$, from (20) he obtained

$$\sqrt{3} = 3x - x^3. \tag{21}$$

Having $\sqrt{3}$ in (21) did not please Al-Biruni. So he chose $2 \cos 20° = x$ and employing the identity

$$\cos 60° = 4 \cos^3 20° - 3 \cos 20°, \tag{22}$$

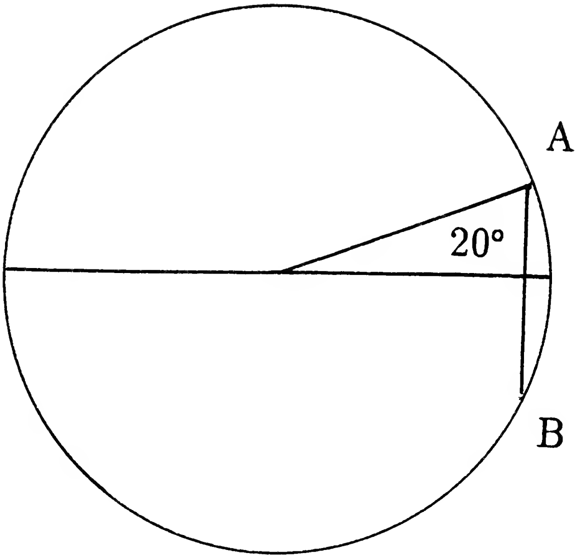

Fig. 4

he obtained

$$x^3 - 3x - 1 = 0. \tag{23}$$

Since (23) can not be factored, there is no ruler-compass construction for the regular nonagon. So Khayyam's construction is employed.

Before the construction, it is mentioned that Sarafal-Din Al-Jusi, a student of Al-Biruni has approximated the positive root of (23) as $x \cong 1.8793852418$. One may study the graph of $y = x^3 - 3x - 1$ and show that (23) has two negative roots and one positive one.

Now in order to obtain the roots of (14), both sides of (23) are multiplied by x and

$$x^4 - 3x^2 - x = 0, \tag{24}$$

Setting $x^2 = y$ in (24)

$$\begin{cases} x^2 = y \\ y^2 - 3y - x = 0. \end{cases} \tag{25}$$

From (25) the circle

$$x^2 + y^2 - 4x - x = 0 \tag{26}$$

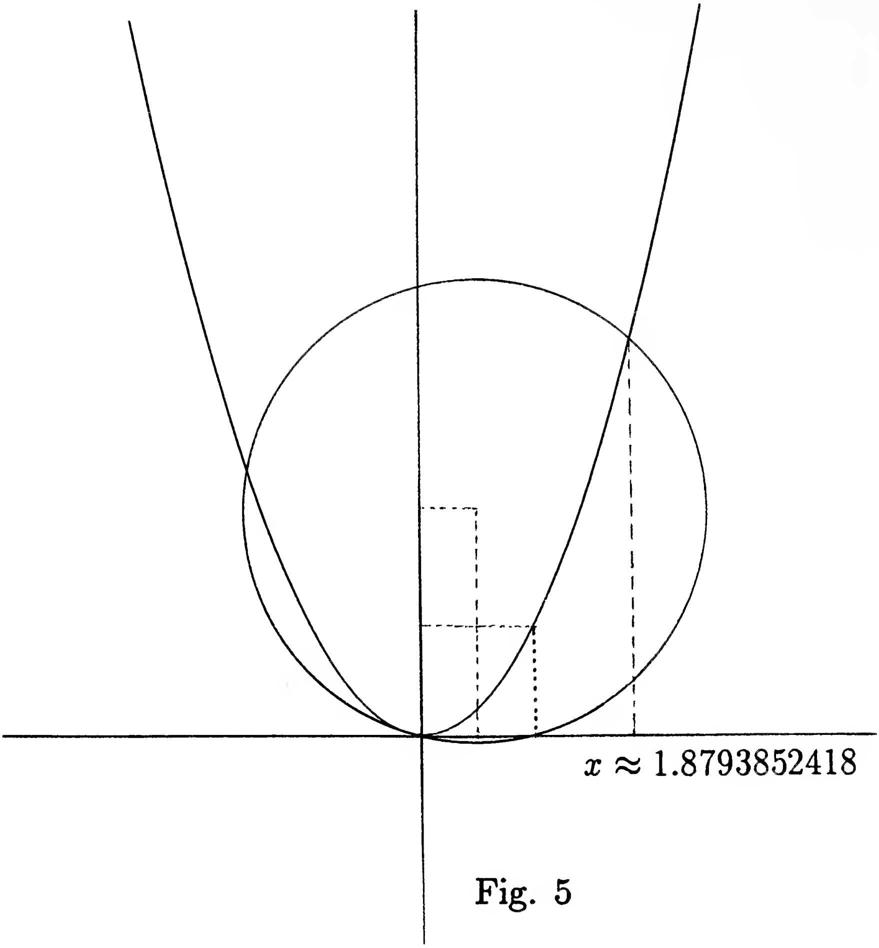

Fig. 5

is obtained or

$$\left(x-\frac{1}{2}\right)^2+(y-2)^2=\frac{17}{4}. \tag{27}$$

Therefore, from the points of intersection of (27) and $y = x^2$ the roots of (23) are obtained (Fig. 5). Note that the circle (27) passes through the origin and its center is at (1/2, 2).

Regular Heptagon

Gauss' technique is chosen to obtain an equation for construction of a regular heptagon in a unit circle.

A unit circle is chosen, i.e., a circle of radius one (Fig. 6). dividing this circle into seven equal arcs is related to the equation

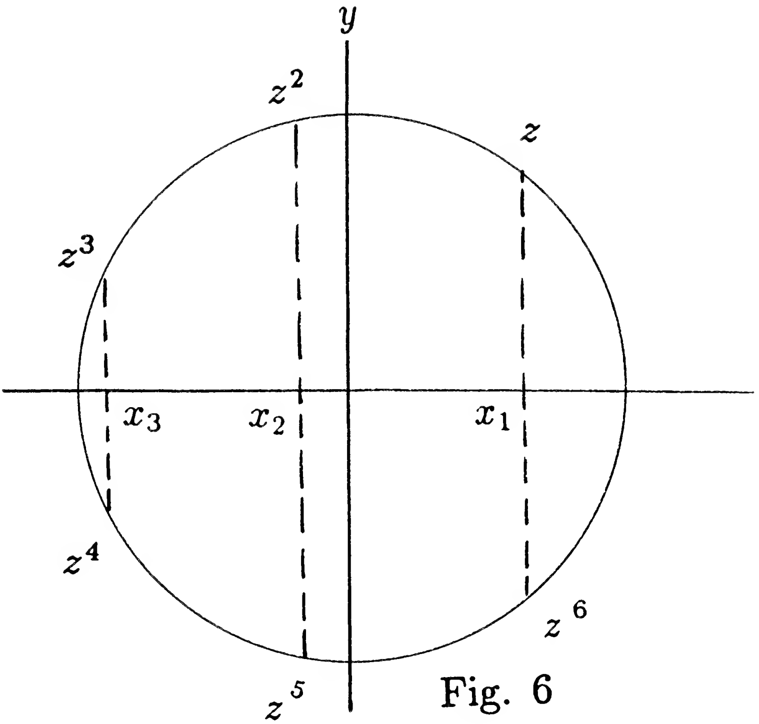

Fig. 6

$$z^7 - 1 = 0. \tag{28}$$

Factoring (28) as

$$(z-1)(z^6+z^5+z^4+z^3+z^2+z+1) = 0. \tag{29}$$

Note that the root $z = 1$ corresponds to (1,0) in (Fig. 6). Other roots are of the form

$$z_k = \cos\frac{2\pi + 2k\pi}{7} + i\sin\frac{2\pi + 2k\pi}{7},\ k = 0, 1, \ldots, 6. \tag{30}$$

Let the roots be $z_0 = 1$, and $z_1 = z, z_2, \ldots, z_6$. Then

$$z_k = z^k,\ k = 1, \ldots, 6. \tag{31}$$

Let z^* denote the conjugate of z. Then

$$z_h^* = z_{7-h},\ h = 4, 5, 6. \tag{32}$$

Now let

$$z_k = x_k + iy_k, \tag{33}$$

then

$$z_k + z^*_{7-k} = 2x_k,\ k = 1,2,3. \tag{34}$$

From (34),

$$\begin{cases} z_1 + z_6 = z + z^6 = 2x_1, \\ z_2 + z_5 = z^2 + z^5 = 2x_2, \\ z_3 + z_4 = z^3 + z^4 = 2x_3. \end{cases} \tag{35}$$

Therefore,

$$2(x_1 + x_2 + x_3) = z + z^2 + z^3 + z^4 + z^5 + z^6 = -1,$$

$$\begin{cases} 4x_1x_2 = (z + z^6)(z^2 + z^5) = z^3 + z^6 + z + z^4 = 2(x_1 + x_3), \\ 4x_1x_3 = (z + z^6)(z^3 + z^4) = z^4 + z^5 + z^2 + z^3 = 2(x_2 + x_3), \\ 4x_2x_3 = (z^2 + z^5)(z^3 + z^4) = z^5 + z^6 + z + z^2 = 2(x_1 + x_2), \end{cases} \tag{36}$$

So

$$x_1x_2 + x_1x_3 + x_2x_3 = x_1 + x_2 + x_3 = -\frac{1}{2}. \tag{37}$$

Finally

$$8x_1x_2x_3 = (z + z^6)(z^2 + z^5)(z^3 + z^4) =$$

$$1 + (1 + z + z^2 + z^3 + z^4 + z^5 + z^6) = 1,$$

which implies

$$x_1x_2x_3 = \frac{1}{8}. \tag{38}$$

From (36), (37), and (38) it is concluded that x_1, x_2, x_3 satisfy the cubic equation

$$x^3 + \frac{1}{2} x^2 - \frac{1}{2} x - \frac{1}{8} = 0. \tag{39}$$

Since (39) can not be factored, there is no ruler-compass construction for the regular heptagon. So, using Khayyam's technique change the variable

$$x = t - \frac{1}{6}. \tag{40}$$

Thus (39) will become

$$t^3 - \frac{7}{12} t - \frac{7}{216} = 0. \tag{41}$$

Comparing (41) with (6) and (9), the corresponding circle will have the center

$$\left(\frac{7}{432}, \frac{19}{24}\right). \tag{42}$$

Since the circle passes through the origin it does not need the radius. Finally x is obtained from (40).

THE CUBE ROOT OF TWO

By the cube root of two is meant the real root of the equation

$$x^3 - 2 = 0. \tag{43}$$

Multiply both sides of (43) by x and obtain

$$x^4 - 2x = 0. \tag{44}$$

Add the extraneous root $x = 0$ to roots of (43). And consider

$$y = x^2. \tag{45}$$

So (44) and (45) will give

$$\begin{cases} y^2 - 2x = 0 \\ y = x^2. \end{cases} \tag{46}$$

The points of intersection of these parabolas will give the roots of (44). Note that (46) is equivalent to

$$\begin{cases} y = x^2 \\ x^2 + y^2 - 2x - y = 0. \end{cases} \tag{47}$$

Thus, the problem amounts to obtaining the points of intersection of the parabola $y = x^2$ and the circle

$$(x - 1)^2 + (y - \frac{1}{2}) = \frac{5}{4}. \tag{48}$$

This circle passes through the origin and its center is at $\left(1, \frac{1}{2}\right)$. Consequently, drawing the parabola and the circle, M is obtained, the point of intersection of these curves whose abscissa (x) is the real solution of (43) (Fig. 7). Note that there is no interest in the extraneous root $x = 0$. The other two roots of (44) are complex.

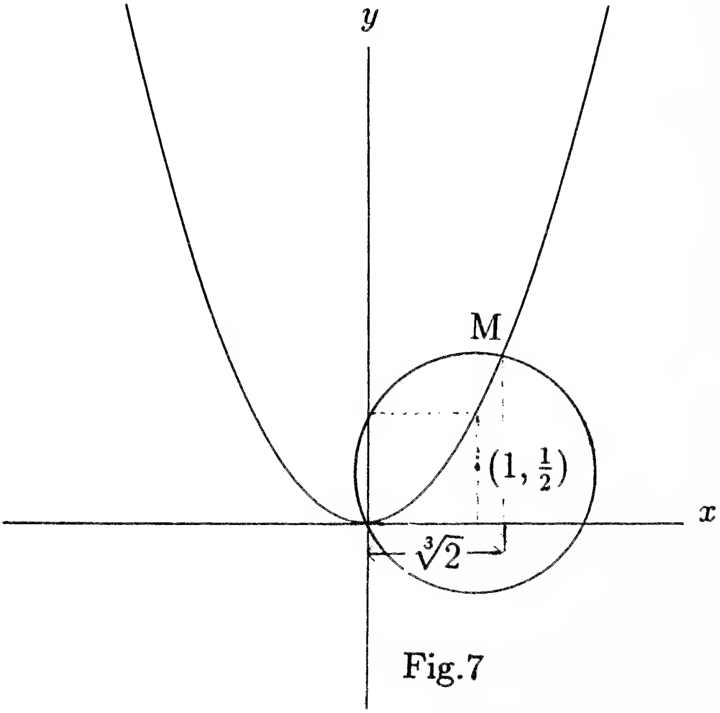

Fig.7

THE CUBE DUPLICATION

What was studied in the previous section is really the solution of cube duplication:

"Given a cube of the edge a, construct a cube whose volume is $2a^3$."

Let the edge of the new cube be x, then

$$x^3 = 2a^3. \tag{49}$$

The solution is

$$x = \mathrm{a} \sqrt[3]{2}. \tag{50}$$

Since, in geometric constructions, the choice of unit is arbitrary, one may choose a to be the unit of length.

Having constructed $\sqrt[3]{2}$, as was done in the previous section, the cube of the edge $\sqrt[3]{2}$, is constructed.

ARCHIMEDES' PROBLEM

Before general solutions of cubic equations were known, Archimedes' problem was the subject of study and research because the problem required solving a cubic equation. In this expository article, the problem is looked at from a new point of view.

THE PROBLEM

Cut a given sphere by a plane so that the ratio of the volumes of the two segments is a given value.

Archimedes reduced the problem to the equation

$$x^3 + c^2b = cx^2. \tag{51}$$

He solved this equation by the intersection of the parabola

$$x^2 = \frac{a^2}{c} y, \tag{52}$$

and the hyuperbola

$$y(\mathrm{c} - x) = bc. \tag{53}$$

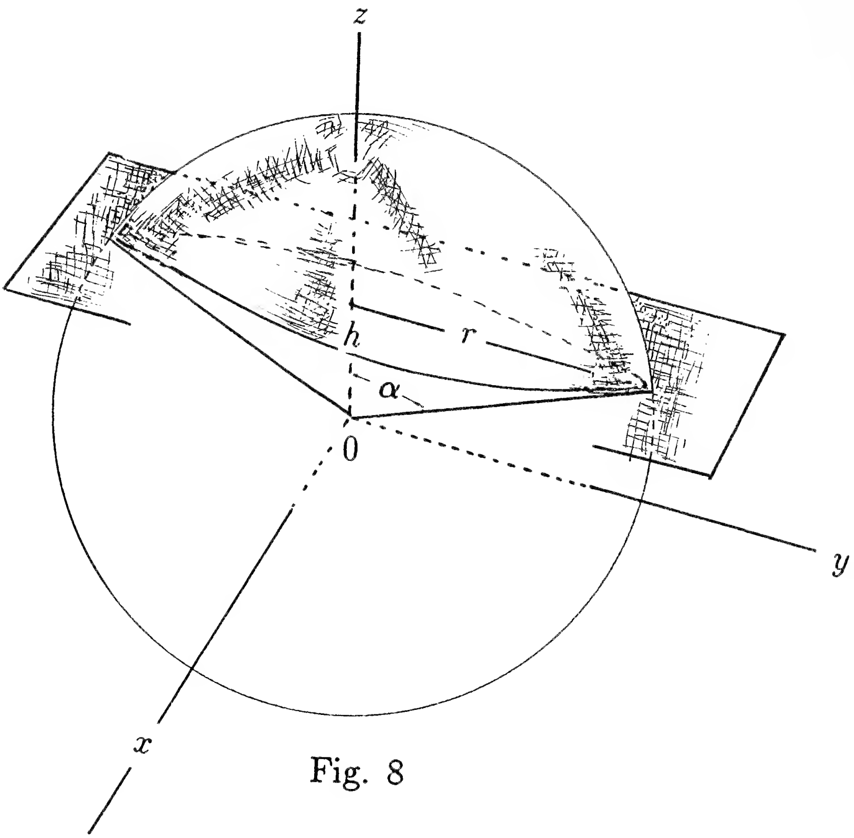

Fig. 8

The equation (51) has been studied by many mathematicians and it was called Mahani's equation.

The Volumes of Sections

Spherical coordinates are used to compute the volumes of the sections (Fig. 8).

Let the equation of the shere by

$$\rho = a, \tag{54}$$

and the plane be

$$z = h. \tag{55}$$

First the volume of the intersection of the sphere and the cone is found

$$\varphi = \alpha. \tag{56}$$

This volume will be

$$\mathcal{V} = \int_0^{2\pi}\int_0^{\alpha}\int_0^{a} \rho^2 \sin \varphi d\rho d\varphi d\theta = \frac{2\pi a^3}{3}(1 - \cos \alpha). \qquad (57)$$

Note that h is $a \cos \alpha$.

Now let the volume of the segment of the sphere above $z = h$ bc $\mathcal{V}_1$.

Then in order to obtain $\mathcal{V}_1$ subtract the volume of the cone $\varphi = \alpha$ which is below $z = h$ from $\mathcal{V}$. So the volume of the cone is:

$$\frac{\pi r^2 h}{3} = \frac{\pi a^3 \sin^2 \alpha \cos \alpha}{3}. \qquad (58)$$

Therefore

$$\mathcal{V}_1 = \frac{2\pi a^3}{3}(1 - \cos \alpha) - \frac{\pi a^3}{3} \sin^2 \alpha \cos \alpha$$

$$= \frac{\pi a^3}{3}(2 - 2 \cos \alpha - \cos \alpha \sin^2 \alpha). \qquad (59)$$

Now let the volume of the segment of the sphere below $z = h$ be $\mathcal{V}_2$. Then

$$\mathcal{V}_2 = \frac{4\pi a^3}{3} - \frac{\pi a^2}{3}(2 - 2 \cos \alpha - \cos \alpha \sin^2 \alpha)$$

$$= \frac{\pi a^3}{3}(2 + 2 \cos \alpha + \cos \alpha \sin^2 \alpha). \qquad (60)$$

ARCHIMEDES EQUATION

To study the problem algebraically, let the ratio of $\mathcal{V}_2 \div \mathcal{V}_1$ be k. Then

$$\frac{2 + 2 \cos \alpha + \cos \alpha \sin^2 \alpha}{2 - 2 \cos \alpha - \cos \alpha \sin^2 \alpha} = k \qquad (61)$$

which gives the equation

$$(1 + k) \cos \alpha \sin^2 \alpha + 2(1 + k) \cos \alpha + 2(1 - k) = 0. \qquad (62)$$

If $k = 1$, then

$$\cos \alpha \, [\sin^2 \alpha + 2] = 0 \qquad (63)$$

which implies that $\alpha = \frac{\pi}{2}$ and $h = 0$.

Since $h = a \cos \alpha$ choose $x = \cos \alpha$ to be the unknown in (62). So

$$x^3 + 3x + \frac{2(1-k)}{1+k} = 0. \tag{64}$$

Using the technique of Omar Khayyam in constructing the roots of (64). Let $\frac{2(1-k)}{1+k} = p$. So (14) can be written as

$$x^3 + 3x + p = 0 \tag{65}$$

Multiply (15) by x and get

$$x^4 + 3x^2 + px = 0. \tag{66}$$

Consider the parabola $y = x^2$, then the solution of (66) amounts to solving the system of equations

$$\begin{cases} y^2 + 3y + px = 0 \\ x^2 - y = 0 \end{cases} \tag{67}$$

Note that (67) is equivalent to

$$\begin{cases} y = x^2 \\ x^2 + y^2 + 2y + px = 0 \end{cases} \tag{68}$$

This set of equations is the same as obtaining the intersection of the circle

$$x^2 + y^2 + 2y + px = 0 \tag{69}$$

and the parabola

$$y = x^2. \tag{70}$$

The parabola and the circle can be constructed accurately (Fig. 9). Observe that the center of the circle (69) is at $(\frac{-p}{2}, -1)$. Note that since k is larger than one, $\frac{-p}{2}$ is positive.

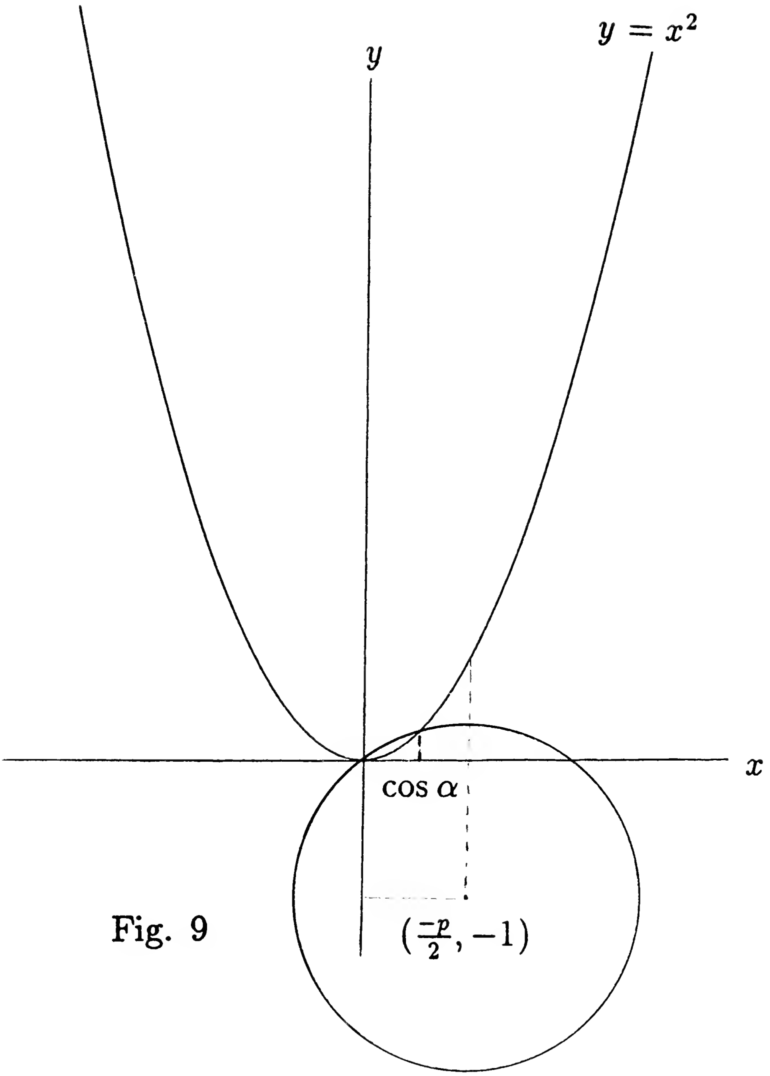

Fig. 9

SUMMARY

The geometric solution of a quartic equation by the use of circles and $y = x^2$ has been presented. The technique has been applied to constructions of Khayyyam's problem, regular monagons, regular heptagon, cube duplication, and Archimedes' problem.

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POPULATIONAL RELATIONSHIPS IN THE CORN SNAKE *ELAPHE GUTTATA* (REPTILIA: SERPENTES)

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ABSTRACT.—A southeastern subspecies, *Elaphe guttata meahllmorum* subsp. nov., is distinct from a northwestern subspecies, *E. g. emoryi*, on the basis of having fewer dorsal blotches on body (44.5 or fewer, 100%, vs 45 or more, 98%, respectively), as well as less distinct differences in ventrals, caudals and ventral pattern. The former agrees with *E. g. guttata* in number of dorsal blotches on body, differing primarily in color from it (gray or brown vs reddish, respectively). *E. g. emoryi* agrees with *E. g. meahllmorum* in color, but differs from both of the other subspecies in having numerous blotches. The eastern, nominotypical subspecies appears to be dichopatric relative to the other subspecies, but if a contact occurs it is with *E. g. meahllmorum*, not with *E. g. emoryi*. The latter two subspecies have parapatric ranges and presumably intergrade, although conclusive evidence is lacking. One nominal species, *Coluber maculatus* Bonnaterre (1790), commonly referred to the synonymy of *E. g. guttata*, was found to be based partly also on *Lampropeltis c. calligaster* (Harlan, 1827). Since no type had previously been specified for *C. maculatus*, a lectotype is designated that maintains the current allocation of the name, thus avoiding replacement of Harlan's name were the *Lampropeltis* selected as lectotype.

RESUMEN. Una subespecie sureste, *Elaphe guttata meahllmorum* subsp. nov., se distingue de la subespecie noroeste, *E. g. emoryi*, por tener menos manchas dorsales sobre el cuerpo (44.5 o menos, 100%, vs 45 o más, 98%, respectivamente), con tambien diferencias no tan prominente en el número de escamas ventrales y caudales, y en el patrón ventral. La primera subespecie comporte con *E. g. guttata* el número de manchas dorsales sobre el cuerpo, pero se diferencia en color (gris o moreno vs rojizo, respectivamente). *E. g. emoryi* comporte con *E. g. meahllmorum* el color, pero se diferencia con ambos las otras en tener manchas más numerosas. La subespecie nominotipical del sureste parece ser dicopátrico con las otras subespecies, pero si contacto ocurre es con *E. g. meahllmorum*, no con *E. g. emoryi*. Las últimas dos subespecies tienen distribuciones parapátricas y por presunción son intergradiente, aunque no hay evidencia conclusiva. Una especie nominal, *Coluber maculatus* Bonnaterre (1790), antes referido a la sinonimía junior de *E. g. guttata*, fue descubrido fundida en parte sobre *Lampropeltis c. calligaster* (Harlan, 1827). Hasta ahora no tipo ha sido designado para *C. maculatus*; para evitar la posibilidad de asignar este nombre a la especie de Harlan, hacemos el lectotipo como un ejemplo de Bonnaterre que pertenece a la especie conocido como *E. g. guttata*, de cual *C. maculatus* definitivemente ahora es un sinónimo junior.

The field of herpetoculture, involving basic research on husbandry and propagation as well as sale of captive-produced animals, has become a multimillion dollar business (Collins, 1992). A species that has been extensively reproduced and that accounts for an important segment of commercial sales is the corn snake, *Elaphe guttata.* The nominate subspecies (*E. g. guttata*) has dominated the attention of herpetoculturists, and numerous color and pattern varieties have been produced by breeders. The western subspecies (great plains rat snake, *E. g. emoryi*), however, has also given rise to some unusual varieties (see below) and it is likely that herpetocultural attention will eventually expand to include this race. Anticipating this shift, we have reexamined the taxonomic status of *E. g emoryi,* concluding that it should be split into two subspecies. This paper represents the evidence that leads to our conclusion together with an analysis of the nomenclatural history of the *E. guttata* complex.

Over 50 years ago, Woodbury and Woodbury (1942) differentiated a subspecies of snake, then known as *Elaphe laeta* (Baird and Girard, 1853), from the nominotypical and only other subspecies, *E. l. laeta.* They named it *E. l. intermontanus* (an incorrect ending; properly corrected to an *-a* ending by Dowling, 1951a) in reference to the isolated population, from which the type was chosen, occurring in central eastern Utah and adjacent Colorado, between the Wasatch and Rocky Mountain ranges. Comparisons were made primarily between the intermontane group and the populations of southern Texas, although specimens from Nebraska, Kansas and New Mexico that they considered intermediate between the nominotypical subspecies and *E. l. intermontanus* were also studied. Excluding those specimens, the Woodburys found a sharp distinction with very little (males) or no (females) overlap between the compared populations in numbers of ventrals and dorsal blotches.

Dowling (1951a) reported that the name *Scotophis laetus* of Baird and Girard (1853), erroneously applied by subsequent workers to the Great Plains Rat Snake, actually is a junior synonym of *Coluber obsoletus* Say (1823), now *Elaphe obsoleta,* and revived the next earliest name, *Scotophis emoryi* Baird and Girard (1853) for the species formerly known as *E. laeta. Scotophis* having been synonymized with *Elaphe* (Stejneger, 1907: 307), the proper nomenclatural combination became *E. emoryi* (Baird and Girard, 1853). Dowling recognized both *E. e. emoryi* and *E. e. intermontana.*

A year later, however, in a checklist of American members of *Elaphe,* Dowling (1952) lumped *E. emoryi* with the taxon described earlier (Linnaeus, 1758) as *Coluber guttatus,* retaining the former as a subspecies of the latter, *E. guttata emoryi.* With the latter he synonymized *E. emoryi intermontana,* without explanation. Such was his authority that without further documentation Woodbury and Woodbury's *E. l. intermontana* has been accepted as invalid by most authors ever since then; exceptions are Wright and Wright (1957), Maslin (1959), Miller (1961) and Weir (1993).

An unpublished master's degree dissertation (Thomas, 1974) did, however, document the untenability of *E. l. intermontana*, but at the same time refuted the validity of all other subspecies of *E. guttata—E. g. rosacea* (Cope, 1860), which had commonly been accepted as a valid species or subspecies since Barbour's (1920) resurrection of it, as well as *E. g. emoryi.* Duellman and Schwartz (1958: 298-300) had already rejected *E. g. rosacea* as a valid subspecies, and that arrangement, with but two subspecies of *E. guttata*, has almost universally been accepted since then, in spite of Thomas' (1974) conclusion.

The original intent was to determine whether the variation occurring in *E. g. emoryi* was based on artifacts of sampling, or significant geographic variation. To the authors' surprise, it was found that the separation envisioned by the Woodburys (1942) and reiterated by Weir (1993) was basically sound, even though the numbers of ventrals, caudals and tail blotches proved to be only marginally useful. The number of dorsal blotches on body, however, was found to vary in a geographically consistent, non-clinal pattern indicative of subspecific status of two groups of populations, although not exactly as conceived by the Woodburys or Weir. The isolated population of eastern Utah and western Colorado is not taxonomically distinct on the basis of morphological characters, limited to small size and usual dark gray background color - so dark in some that the dorsal blotches are difficult or impossible to count. Isozyme evidence would be useful in reconsideration of the isolate's taxonomic status.

Although an increase in number of dorsal blotches toward the northern part of the range of *E. g. emoryi* (sensu lato) has long been noted (e. g. Thomas, 1974; Conant and Collins, 1991: 196), and in some cases interpreted simply as a phenotypic effect of a temperature cline, in reality the race with few blotches (to the southeast) reaches nearly to the northernmost limit of the range of *E. g. emoryi* (s.l.), in southwestern Illinois, and the race with more numerous blotches (to the northwest, *E. g. emoryi*, sensu stricto) extends southward to about 29° N latitude, south of San Antonio, Texas (Fig. 1). Temperature effects are therefore essentially ruled out (see also statistical analyses reported below).

MATERIALS AND METHODS

410 specimens were studied referable to *E. g. emoryi* (s.l.), representing all parts of its range except Louisiana, extreme eastern Texas and southern Arkansas. Range limits (Fig. 1) have been conceived on the bases of those specimens, Conant and Collins (1991) and Dundee and Rossman (1989). All specimens in the 13 acknowledged collections have been examined except for a few duplicates in UNM. Standard scutellational and mensural data were taken on 178 specimens randomly representative of the geographic range of the subspecies (s.l.) as a whole (Tables 3, 4). On the remaining 232 the only

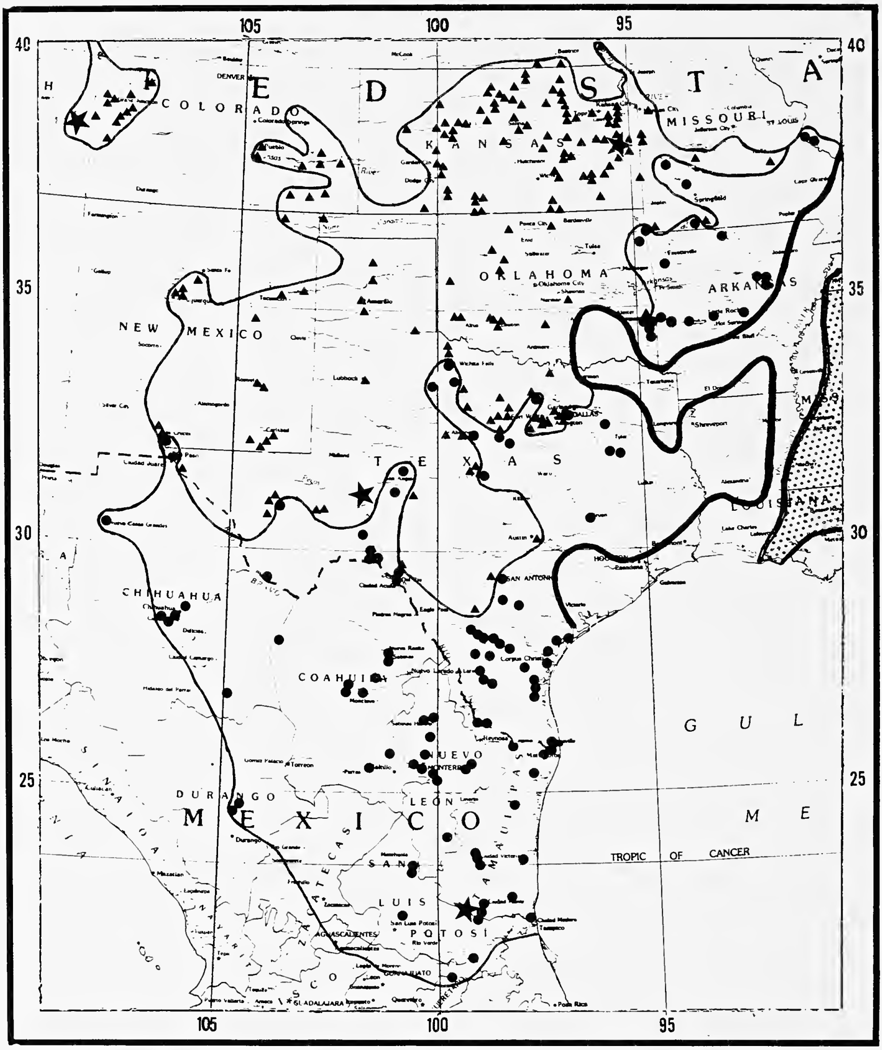

FIGURE 1. Distribution of *Elaphe guttata emoryi* (triangular dots) and *E. g. meahllmorum* (circular dots). Stars indicate type localities of *Scotophis emoryi* (Texas), *E. l. intermontanus* (Utah), *E. g. meahllmorum* (San Luis Potosi), and *Coluber rhinomegas* (Kansas). Symbols denote localities represented by specimens examined except for the type localities of *S. emoryi* and *C. rhinomegas*. The stippled area indicates the range of *E. g. guttata*, which barely enters the depicted area. The heavy black line outlines eastern areas where the species apparently does not occur. Thinner lines outline the suggested ranges of the two western subspecies. Range limits are based on material studied, Conant and Collins (1991: map 167), Chiszar et al. (1992) and Dundee and Rossman (1989: 231). Base map adapted from U.S. Geological Survey 1:10,000,000 1982 map of North America.

scutellational data taken were ventral and caudal counts (Tables 1, 2). Ventrals were counted by the Dowling (1951b) system.

Five sets of data were taken on the pattern of all 410 specimens (Tables 1, 2). The dorsal blotches on the body were counted beginning with the first blotch on the neck posterior to the two cranionuchal stripes, but because of the frequent occurrence of transversely Y-shaped blotches, two sides were counted separately and statistically analyzed for the mean figures for each specimen, resulting in some fractional counts (e.g., 35.5). Such aberrations were more numerous in populations with more numerous blotches (*E. g. emoryi* sensu stricto) than in those with fewer.

The number of dorsal blotches on the tail was also recorded for all specimens.

The number of ventrals with submedial spots appeared early in the study to be greater, especially on the anterior part of the venter, in *E. g. emoryi* (s.s.), hence two counts were made on all specimens to reflect that difference: (1) the number of ventrals with submedial dark spots among the first (anterior) 50 ventrals, and (2) the first (anterior) ventral bearing one or more submedial spots. Care had to be exercised to disregard the lateral blotches that involve the lateral ends of the ventrals; they are regularly present whereas the more medial spots, usually to one side of midline, are highly variable, occurring on anywhere from no ventrals at all to almost all of them. Evidently variation of the two sets of spots is under different genetic control.

In addition to the specimens personally examined, data on 60 specimens of *E. g. guttata* in the files originally created by Frank N. Blanchard were utilized. Those files were passed on to Howard K. Gloyd and ultimately were given to HMS.

All museum alphabetisms (they are not, as a rule, acronyms; Algeo and Algeo, 1991:9) are conformant with Leviton et al., 1980, insofar as given; others are: ASUMZ, Arkansas State University Museum of Zoology, State University, Arkansas; EAL, Ernest A. Liner, Houma, Louisiana; UTEP, University of Texas at El Paso; and WTAM, West Texas A&M University, Canyon, Texas.

RESULTS

No characters were found to provide acceptable diagnostic differentiation of the two subspecies except for the number of dorsal blotches on the body, although several other characters exhibited significant differences (see Variation and Comparisons for statistical analyses). The pattern of variation nevertheless is indicative of the validity of two subspecies in the populations formerly referred to *E. g. emoryi*. Since the race with fewer blotches has never received a distinctive name, the authors here call it *Elaphe guttata meahllmorum*, subsp. nov.

Holotype. UCM 46009, El Salto, San Luis Potosí, Mexico, June 13, 1964, T. Paul Maslin et al. (the UCM "Yucatán Expedition").

Paratypes. Forty-one; states (and counties in the United States) as follows (see list of Specimens Examined for more precise locality data). Arkansas: Cleburne (MPM 17000, 19100), Saline (ASUMZ 18304), Washington (UAM 68-735-1833). Illinois: Monroe (UIMNH 50963). Missouri: Taney (KU 19093). Texas: Cameron (UCM 15232, 15234, UTA 8404), Duval (UTA 17179), Jim Hogg (KU 174799, UTA 10439), Karnes (WTSU 8766), LaSalle (UTA 16780), McMullen (UTA 10428, 16662), Nueces (KU 61001), San Patricio (EAL 255), Starr (UTA

17784), Van Zandt (UTA 15809), Webb (KU 145867). Chihuahua: EAL 2535, UNM 3430. Coahuila: EAL 7, 2391, 2420, KU 47100, UTEP 6336. Nuevo León: EAL 669, 1187, 2603, KU 87743, UCM 47378, UO 33466. Querétaro: UTEP 9116. San Luis Potosí: EAL 323, KU 67652, UTA 4674. Tamaulipas: KU 61008-9, UCM 50118.

Definition/Diagnosis. A member of the *E. guttata* complex, having "parallel neck stripes crossing the parietals and normally uniting on the frontal" (Thomas, 1974:57); no ontogenetic change in pattern; a postorbital stripe extending onto or beyond infralabials; ventrals and subcaudals not exceeding 232 and 86 in males, 240 and 83 in females, respectively (Thomas, 1974:98); venter usually distinctly checkerboard-like in pattern, light areas between dark rectangles usually white, sharply contrasting with pigmented areas; usually two, largely continuous black stripes on subcaudal surface. Distinct from *E. g. guttata* in having dark gray, olive, or gray-brown dorsal blotches on a light gray background (vs reddish or orange blotches and ground color), and from *E. g. emoryi* in having 44.5 or fewer dorsal blotches on body (100%, vs 2%).

Description of holotype. A young adult female, s-v 517 mm, tail 113 mm, tail/total length ratio 0.1794. Specimen well preserved and in good condition except for a deep cut on right side of neck from midline between posterior genials to level of ventral 14, and a more superficial cut on left side between levels of ventrals 20 and 34.

Preoculars 1-1; postoculars 2-2; temporals 2-2-3 on both sides; supralabials 8-8; infralabials 12-12; scale rows 25-29-19; ventrals 223; subcaudals 71 (plus 2-4 missing at tip); anal divided; median dorsals weakly keeled, beginning with the vertebral scale row posterior to the anterior third of body (where all dorsals are smooth) and increasing within a span of 20 ventrals to the median eight rows; no keels on tail, others smooth or very faintly keeled; two apical pits on all dorsal scales of both body and tail, except erratic (present, absent or only one of the pair, usually the more medial one, present) on the first dorsal scale row.

Dark markings gray-brown, black-edged; a dark bar across internasals, extending onto supralabials and rostral; an interorbital dark bar continuous with a postocular dark bar ending on infralabials at rictus oris; a pair of longitudinal, short cranionuchal dark stripes beginning posteriorly at level of ventral five, uniting on frontal; right cranionuchal dark stripe narrowly connected with first blotch on trunk; a small, elongate, medial dark spot on posterior extremity of interparietal suture, extending posteriorly onto anterior three rows of nuchals; 35 dorsal dark blotches on body, 13 on tail; body blotches mostly about as broad as long, extending to 7th-9th-5th scale rows (anterior, middle, rear trunk regions), separated medially by spaces about 1.5 scale rows long; most of the anterior blotches with a transverse light area surrounding black-centered scales; 25th blotch more elongate than others and almost completely split by that transverse light area with black-centered scales (much like the 9th blotch shown in Fig. 2); lateral spots distinct, relatively large (0.25 size of dorsal blotches), mostly alternating with dorsal blotches, not reaching ventrals, but alternating or coinciding with small, more numerous sublateral spots (covering the equivalent of 2-5 dorsal scales) that encroach onto the ends of the ventrals.

First ventral with a median or paramedian dark spot, no. 17; 17 ventrals among the anterior 50 with one or more such spots; little scattered pigment on venter between spots; checkered ventral pattern moderately dense, approximately 2/3 of ventrals involved; paired subcaudal stripes continuous only on posterior 3/5 of tail.

Etymology. The subspecific name *meahllmorum* (pronounced as though spelled "meal/morum") is derived from the names of 11 associates of HMS to whom he is indebted particularly for absolutely vital aid in preparation for publication of volume seven of the series jointly authored by himself and his wife and co-worker, Rozella B. Smith, entitled A Synopsis of the Herpetofauna of Mexico. The new name is a collective, proposed in honor of the following individuals, now or formerly at the University of Colorado, listed with their designated letters in the order of occurrence in the name: m, Dr. Michael J. Preston, Department of English; e, Mary E. Marcotte, EPOB (Department of Environmental, Population and Organismic Biology) secretary; a, Ann E. Carrington, do.; h, Laura J. Heigl, do.; l, Linda K. Bowden, do.; l, Dr. William M Lewis, Chairman, EPOB; m, Dr. Michael D. Breed, EPOB, former Chairman; o, Phyllis A. O'Connell, EPOB secretary; r, Dean Charles R. Middleton, College of Arts and Sciences; u, Dr. Shi-Kuei Wu, Curator of Zoology, University of Colorado Museum; and m, Dr. Michael C. Grant, EPOB, former Chairman.

Variation and Comparisons. Discriminatory variation in *E. g. emoryi* and *E. g. meahllmorum*, based on our data on 410 specimens, and in *E. g. guttata*, based on data for 60 specimens in the Blanchard files, is summarized in Table 1. Statistical tests comparing *E. g. emoryi* and *E. g. meahllmorum*, the primary focus of this paper, are presented in Table 2.

Because the subspecies we call *E. g. meahllmorum* was not recognized in the past, the literature (Thomas, 1974; Raymond and Hardy, 1983; Dundee and Rossman, 1989) indicates that no significant differences in scalation exists between the subspecies of *E. guttata*, but with segregation of the present subspecies we have found them in both ventral and caudal counts. In a number of respects *E. g. meahllmorum*

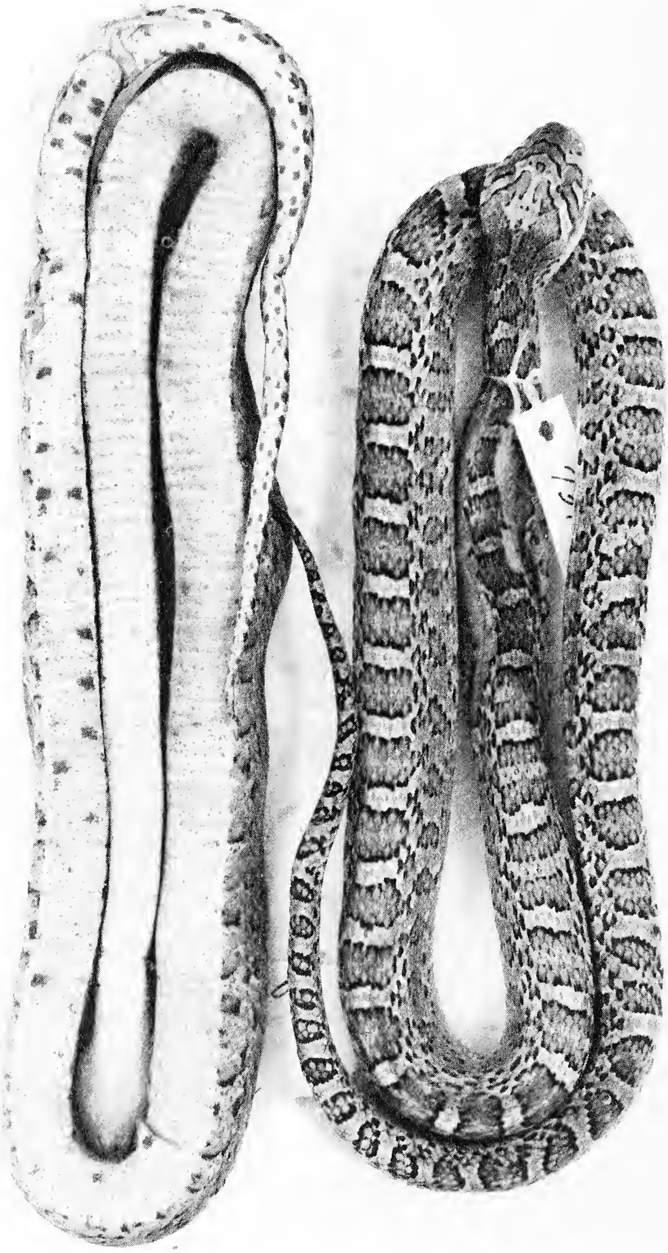

FIGURE 2. Dorsal and ventral views of *E. g. meahllmorum*. Dorsal view, a medium-sized male, EAL 731, 26.2 mi S Riviera, Kleberg Co., in Kenedy Co., Texas, showing the highest degree observed of secondary splitting of dorsal blotches. Ventral view, a medium-sized male, EAL 520, 19.1 mi S Riviera, in Kenedy Co., showing (1) the great reduction in number and sharpness of definition of the ventral spots, (2) the abundant pigment scattered throughout the venter, and (3) the complete absence of paired subcaudal stripes. See text (Variation and Comparisons) for discussion.

TABLE 1. Comparisons of the subspecies of *Elaphe guttata* on continuously distributed characters*.

Character	*emoryi*	*meahllmorum*	*guttata*
Body blotches			
N (range) $\bar{x}$	256 (39.5-73) 51.2	154 (27.5-44.5) 37.3	56 (27-40) 31.8
<45,%	2	100	100
<35.5,%	0	22	86
Tail blotches			
N (range) $\bar{x}$	223 (12-28.5) 20.4	152 (11-23) 15.9	32 (10-16) 12.3
<18.5,%	26	75	100
<16,%	4	25	97
<15,%	2	15	88
Male ventrals			
N (range) $\bar{x}$	159 (197-225) 210.3	102 (201-233) 214.4	27 (211-230) 220
<213,%	72	35	7
<215,%	91	54	15
<218,%	96	72	33
Female ventrals			
N (range) $\bar{x}$	86 (203-228) 216.0	51 (206-236) 221.6	26 (208-238) 227
<220,%	71	29	12
<222,%	83	47	15
<225,%	97	73	31
Male caudals			
N (range) $\bar{x}$	139 (62-77) 69.3	89 (65-83) 75.0	24 (58-76) 69.3
<72,%	77	24	75
Female caudals			
N (range) $\bar{x}$	77 (58-74) 64.2	44 (60-77) 69.1	23 (57-73) 64.0
<72,%	25	68	96
Spotted ventrals in 1st 50			
N (range) $\bar{x}$	245 (0-47) 26.9	153 (0-50) 16.4	
<24,%	31	70	
1st spotted ventral			
N (range) $\bar{x}$	246 (1-205) 12.5	155 (1-226) 26.7	
<11,%	62	40	

*The data for *E. g. guttata* are from the Blanchard files; see Materials and Methods. Data for the remaining subspecies are based on 410 specimens, exclusive of damaged individuals on which certain counts could not be made.

agrees with *E. g. guttata*, or is more or less intermediate between the latter and *E. g. emoryi* (s.s.); lumping *E. g. meahllmorum* and *E. g. emoryi* (s.s.) as *E. g. emoryi* (s.l.) thus tends to eliminate the scalational differences, leaving the reddish coloration of *E. g. guttata* as its sole distinction from the other subspecies.

The number of dorsal blotches on body remains the most reliable distinction between *E. g. emoryi* (s.s.) and the other two subspecies, the former having 45 or more in 98% of examined specimens, as opposed

TABLE 2. Student *t* tests comparing *Elaphe guttata emoryi* (s.s.) and *E. g. meahllmorum* for each character shown in Table 1. Sample sizes are listed in Table 1. Also shown are proportions of variance in each character that are associated with taxa treated as an independent variable and with longitude and latitude treated in the same manner.

			Proportion of variance (r^2) associated with:		
Character	*t*	*P*	taxa	longitude	latitude
Body blotches	29.74	<0.01	0.69*	0.06	0.46
Tail blotches	11.35	<0.01	0.26*	0.11	0.05
Male ventrals	6.22	<0.01	0.13	0.12	0.16
Female ventrals	5.38	<0.01	0.17	0.17	0.17
Male caudals	11.68	<0.01	0.37*	0.04	0.28
Female caudals	7.59	<0.01	0.32	0.21	0.28
Spotted ventrals in 1st 50	9.43	<0.01	0.18	0.17	0.16
1st spotted ventral	6.58	<0.01	0.09	0.10	0.03

*Clinal effects singly or in combination are significantly smaller than the variance between taxa.

to 100% having fewer than 45 in the others. However, *E. g. guttata* has 35 or fewer in 86% of specimens examined, *E. g. meahllmorum* 35.5 or more in 78%. Likewise, 74% of *E. g. emoryi* have 18.5 or more dorsal caudal blotches, as opposed to 25% of *E. g. meahllmorum* and 0% of *E. g. guttata.* In the latter subspecies 88% have fewer than 15 caudal blotches, whereas in *E. g. meahllmorum* only 15% do, and of course only 2% of *E. g. emoryi.* Thus the number of dorsal blotches on body and tail serves as a rather strongly reliable or even infallible criterion for distinguishing all three subspecies from each other.

As shown in Figs. 2-6, considerble variation exists in the markings of both *E. g. emoryi* and *E. g. meahllmorum.* Fig. 2 illustrates the highest degree observed of secondary splitting of dorsal blotches, yielding a possible count of 47 in an animal basically with fewer, certainly no more than 44; because of this ambiguity its dorsal blotch count was not entered in the statistical analyses. Although several other specimens exhibited divided blotches that required separate count, no other was rejected for statistical analysis, because their totals did not exceed the standard limit (44.5) for the subspecies. The key to subspecies is adjusted to extremes exceeding that limit by incorporating notation of the split-blotch tendency.

Fig. 2 also illustrates an example of the extensive reduction in number of ventral spots that is common in *E. g. meahllmorum,* rare in *E. g. emoryi.* Such poorly defined ventral spots, and such abundant, scattered ventral pigment, are rare variants observed only in *E. g. meahllmorum,* although universal in sympatric *E. obsoleta.* The absence or great reduction of the subcaudal stripes occurs much more frequently in *E. g. meahllmorum* than in *E. g. emoryi*; complete

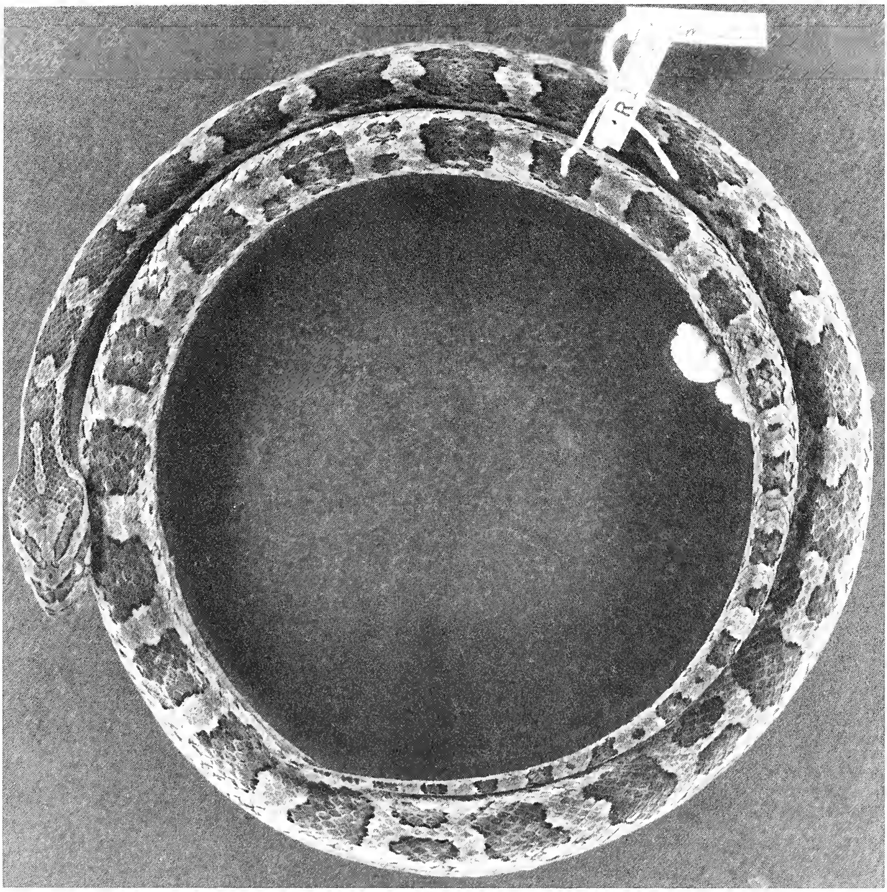

FIGURE 3. *E. g. meahllmorum*, dorsal view, UTA 17784, male, 781 mm tl, showing an unusual variant with some blotches partially split transversely, others constricted at midline, appearing H-shaped, and others, all small, actually split at midline. Specimen from "Rd on S border of federal property behind Falcon Dam, Starr Co., Texas." Dorsal blotches 33.

absence was noted only in material from Texas and Mexico (37 in 129, 29%, higher in Mexico, with 20 in 58, 34%, than in Texas, 17 in 71, 24%) in the former, whereas in *E. g. emoryi* only 4% (11 in 248) had no subcaudal stripes, although the percentage was higher to the south (Texas 5 in 54, 9%, vs 6 in 194 from western Colorado (1), eastern Kansas (3) and northeastern New Mexico (2), 3%.

See Figs. 3-6 for examples and explanations of other pattern variants.

Most important is the fact that clinal variation in both body and tail blotches cannot account for these taxonomic differences (Table 2). Tests of this matter focussed exclusively on *E. g. emoryi* and *E. g.*

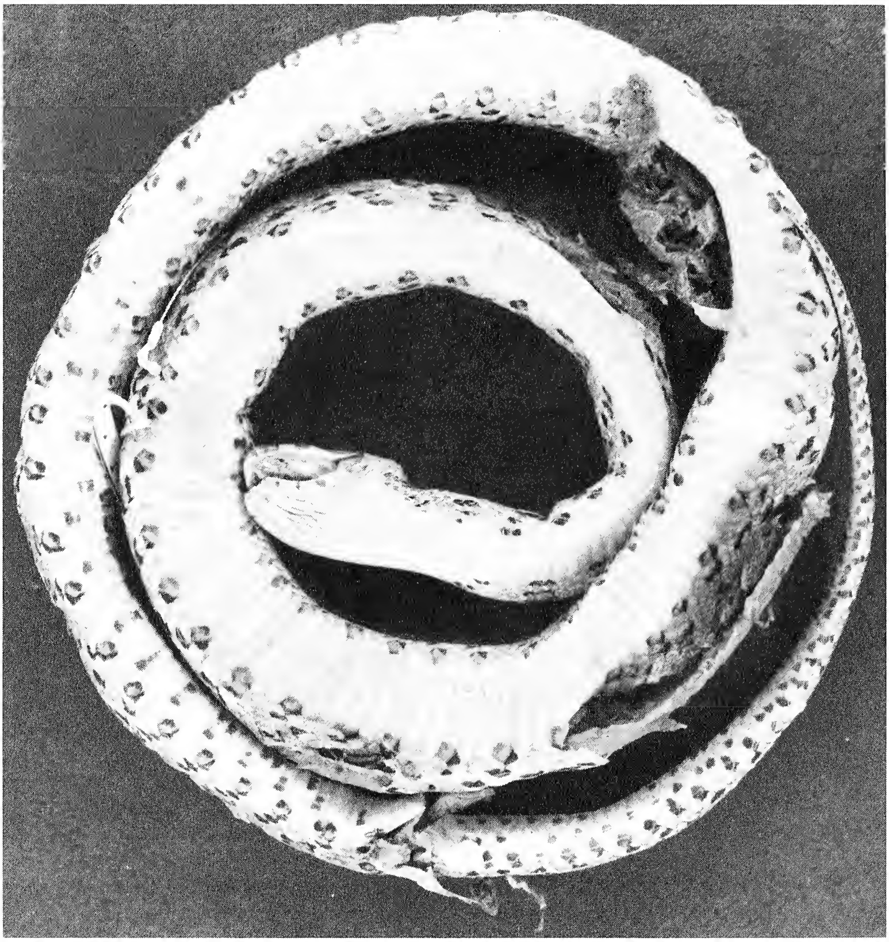

FIGURE 4. *E. g. meahllmorum*, UTA 14733, male, 953 mm tl, Hy 83, 5.6 km W Hy 755, Starr Co. Texas, showing a clear (no scattered pigment) venter with few paramedian dark spots, and no subcaudal stripes.

meahllmorum. Data were pooled over taxa and regressed on longitude and latitude. Both geographical factors were associated with variation in body and tail blotches, but for neither character could clinal effects account for as much variation as was visible between the taxa (Table 2). In this analysis, longitude and latitude were treated as covariates with respect to taxa. Variation in, for example, body blotches was partitioned into the proportions associated with longitude (0.06) and latitude (0.46). When these values were substracted from the proportion of variance associated with taxa (0.69), the difference (0.17) was significantly greater than zero, implying differentiation (presumably from genetic sources) between taxa that cannot be accounted for by

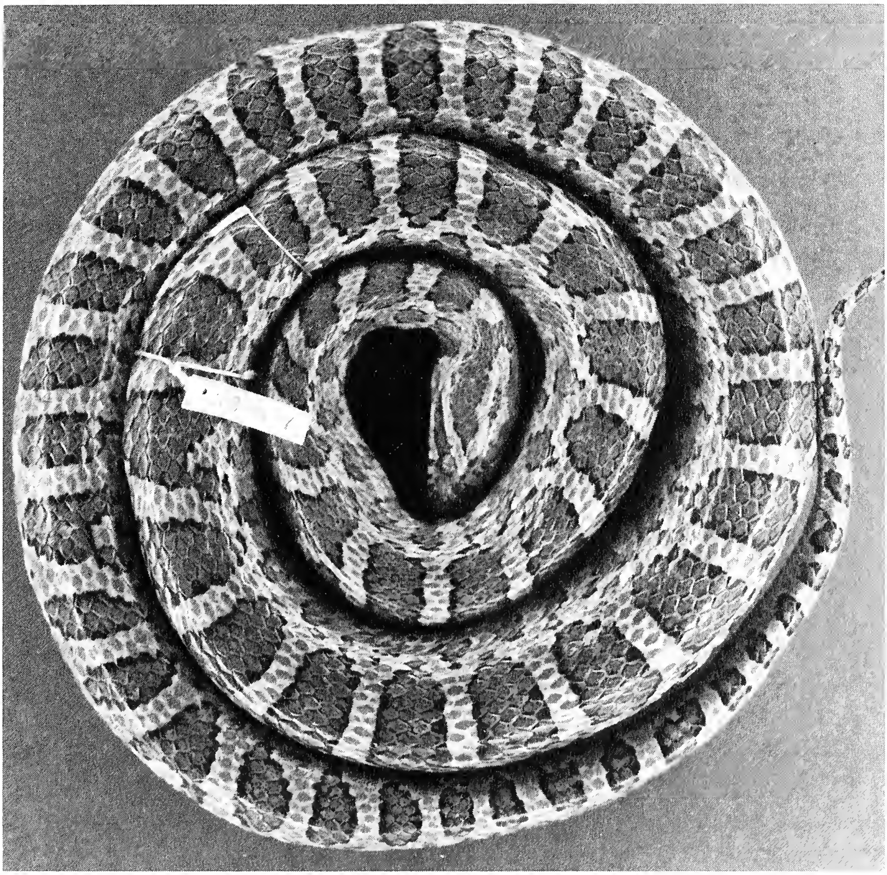

FIGURE 5. *E. g. emoryi*, dorsal view of UTA 30677, male, 1164 mm tl, Wise Co., Texas (no precise locality), with 51/54 (mean 52.5) dorsal blotches on body. Blotches nos. 18, 42 and 45 can be seen divided on one side or the other; each was counted as two blotches on one side, one on the other.

clinal effects. The same outcome arose from our analysis of tail blotches.

Ventrals and caudals also exhibit significant differences between *E. g. emoryi* (s.s.) and *E. g. meahllmorum* (see Tables 1 and 2). However, clinal variation is generally equal to or greater than the taxonomic variation. Therefore, we are reluctant to use these characters for diagnostic purposes. The same conclusion was reached for the last two characters in Tables 1 and 2.

Other variation is summarized in Tables 3 and 4. None of the variables listed here distinguish between *E. g. emoryi* and *E. g. meahllmorum* (all p's < 0.05).

Although it is clear that clinal effects cannot account for all of the variance between *E. g. meahllmorum* and *E. g. emoryi* in either body

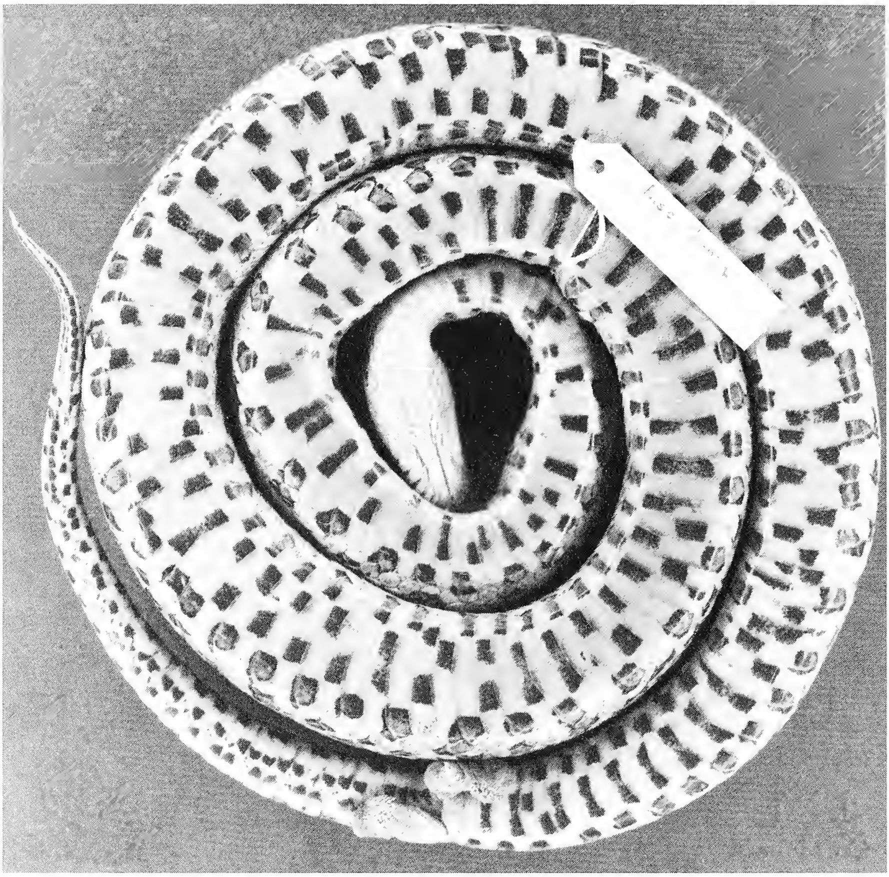

FIGURE 6. *E. g. emoryi*, ventral view of same specimen as in Figure 5, showing the numerous, sharply outlined spots and absence of scattered pigment as is characteristic of most *E. guttata*. The subcaudal stipes are less well defined than in most specimens of this subspecies, and were recorded as 1/4 of the tail length.

blotch counts or tail blotch counts, nevertheless it is acknowledged that substantial clinal variation exists in these and other characters. It therefore seems likely that the phenotypic clinal variance within the subspecies of *E. guttata* will be found to correlate either directly or indirectly with physiographic and climatological forces, by studies that apply the methods of Owen and Dixon (1989) or Ward et al. (1994) to geographic variation in *E. guttata*. Indeed, such efforts are encouraged by the authors because they will lead ultimately to a precise partitioning of phenotypic variation into direct environmental and genetic components, a result that is sorely needed in modern systematics, particularly in applications of the Evolutionary Species Concept.

Table 3. Non-discriminatory, non-sexually variable meristics in the western subspecies of *Elaphe guttata**

	emoryi	*meahllmorum*		*emoryi*	*meahllmorum*
postoculars			post. temporals		
2-?	0	1	2-4	0	1
2-2	102	66	3-3	20	11
2-3	2	2	3-4	22	19
3-3	0	1	3-5	1	2
ant. temporals			4-4	53	32
1-2	1	0	4-5	7	3
2-2	62	31	5-5	0	1
2-3	15	17	preoculars		
3-3	24	21	1-1	101	70
3-4	1	0	2-2	2	0
med. temporals			supralabials		
2-2	12	5	7-8	1	0
2-3	9	5	8-?	1	1
3-3	71	49	8-8	97	58
3-4	10	8	8-9	5	8
4-4	1	1	9-9	0	3
4-5	0	1			
	emoryi	*meahllmorum*	12-13	20	15
infralabials			13-?	0	2
11-?	1	0	13-13	26	14
11-11	6	8	13-14	10	9
11-12	11	1	14-?	1	1
11-14	0	1	14-14	6	6
12-?	1	1	15-16	0	1
12-12	20	9			

*Counts were made on 178 specimens, exclusive of damaged individuals on which certain counts could not be made.

Only one example of the striped variant of the species has been seen by the authors. It is a small (322 mm total length), female *E. g. emoryi*, captive bred, from Ft. Stockton, Pecos Co., Texas (KU 174798). It is anomalous also in having many ventrals divided medially and partially fused, to such an extent that ventral and caudal counts and other measurements were not recorded.

Key to the Subspecies of Elaphe guttata

1. Dorsal ground color and dorsal blotches reddish or pinkish; dorsal blotches on body fewer than 44.5 (100% ?); dorsal tail blotches fewer than 15 (88%); male ventrals more than 217 (67%); female ventrals more than 224 (69%); caudals fewer than 72 in males (75%) and females (96%); east of the Mississippi River........*E. g. guttata*

   Dorsal ground color gray; dorsal blotches gray, olive or gray-brown, 24-73 on body, 11-28.5 on tail; male ventrals fewer than 218

TABLE 4. Non-discriminatory, sexually variable meristics in the western subspecies of *Elaphe guttata**

	Males		Females	
	emoryi	*meahllmorum*	*emoryi*	*meahllmorum*
scale rows, ant.				
23	8	5	3	0
24	2	1	1	0
25	53	43	38	18
26	0	0	0	1
27	0	1	0	0
N	63	50	42	19
Scale rows, midbody				
25	2	1	1	0
26	0	0	1	0
27	54	31	35	11
28	1	1	1	1
29	8	17	4	8
N	65	50	42	20
scale rows, post.				
18	0	1	0	0
19	57	35	22	6
20	2	4	4	2
21	7	10	16	12
N	66	50	42	20

*Counts were made on 178 specimens, exclusive of damaged individuals on which a few counts could not be made.

in at least 72%; female ventrals fewer than 225 in at least 73%; caudals fewer than 72 or not; west of the Mississippi River........2

2. Dorsal blotches on body 45 or more (98%), *and* none tending to be split transversely by a light streak; dorsal tail blotches 18.5 or more (74%); male ventrals fewer than 213 (72%); female ventrals fewer than 220 (71%); male caudals fewer than 72 (77%); female caudals 72 or more (75%)..................................*E. g. emoryi*

   Dorsal blotches on body 44.5 or fewer (100%), unless some show evidence of a transverse split; dorsal tail blotches fewer than 18.5 (75%); male ventrals 213 or more (65%); female ventrals 220 or more (71%); male caudals 72 or more (76%); female caudals fewer than 72 (68%).....................................*E. g. meahllmorum*

Name allocations

In order to be certain that no name previously applied to *E. guttata* pertains to the subspecies here described, it has been necessary to examine all of them. They are here reviewed.

That the name *Scotophis emoryi* Baird and Girard (1853) is properly associated with the northwestern subspecies with numerous dorsal blotches is assured by (1) its type locality (Howard Springs, ≈20 mi SW Ozona, Crockett Co, Texas, fide Dowling, 1951a: 43), which lies within, although near the edge of, the known boundaries of that subspecies; (2) color ("Ground color grayish ash," dorsal blotches "olivaceous brown"), and (3) pattern ("transverse quadrate blotches, 70 in number, the 50th opposite the anus. These are ten or 12 scales broad, two or three long, and separated by intervals of one to two scales. They are narrowly margined with black.") (quotations from the original description, p. 157). The type is lost (Dowling, loc. cit.), but the original description conclusively confirms the allocation here adopted.

Two junior synonyms of *E. g. emoryi* exist. The holotype of *E. l. intermontanus* Woodbury and Woodbury (1942), UU 271 from Moab, Utah, came from the western edge of the range of *E. g. emoryi*, and conforms in color with other material of that subspecies. It has fewer dorsal blotches (43, fide the original description) than average (51.2, Table 1), but 43 is within the known range of variation (39.5-73) in *E. g. emoryi* (s.s.). The dorsal blotch count was very likely not made the same way by the Woodburys as by us, and could be three or four fewer than a count made by our system. We were unable to borrow material from the UU collection.

The other junior synonym of *E. g. emoryi* is *Coluber rhinomegas* Cope (1860), a substitute for *Scotophis calligaster*: Kennicott (1859) (nec Harlan). Unfortunately neither Cope nor Kennicott noted the number of dorsal blotches, but the holotype is USNM 2259 (Cochran, 1961:166). Dr. Kevin de Queiroz very kindly examined it and reported (pers. comm.) its dorsal blotch count as 47, above the 44.5 upper limit for *E. g. meahllmorum*, and within the range of *E. g. emoryi* (s.s.). Our allocation of it to *E. g. emoryi* (s.s.) is based on the type locality. Hyatt, Anderson Co., Kansas, well within the known range of that subspecies, and upon variation of specimens examined from Anderson county and the surrounding area. Three specimens (KU 1057-8, 30072) from that county have 39.5, 47, 47 dorsal blotches on body, and seven from the next county east (Linn, KU 192203, 207170) and from four counties to the south (Bourbon, KU 192204; Montgomery, KU 154029, 154514; Wilson, KU 188691; Woodson, KU 170627) have 47-59.5 (mean 51.1) blotches on body. Therefore the authors regard allocation of *C. rhinomegas* to *E. g. emoryi* as conclusively confirmed.

The history of Kennicott's material from Hyatt, Anderson Co., Kansas - the type locality of both *C. rhinomegas* and *Diadophis arnyi* - is of some interest, inasmuch as no such place name is to be found in recent gazetteers or atlases, even in the extremely detailed U.S. Geological Survey 1:24,000 (7.5 × 7.5 minutes) topographic maps of Anderson county, although numerous names for places no longer in existence are given there. The possibility of error of locality citation for these names, perhaps involving ranges of adjacent subspecies, led us to seek expert help. It was forthcoming from Dorothy Kipper Licktieg of Greeley, Anderson Co., Kansas, president of the Anderson County Historical Society and author of a nearly completed book, the first of three, on the history of the county (Licktieg, 1993). She sent us a copy of a map showing Hyatt on the Missouri Pacific Railway about 3-4 miles southwest of Garnett. According to her information, Hyatt was a Massachusetts colony founded by Thaddeus Hyatt, who befriended and was tainted by association with the then infamous abolitionist John Brown, who in turn was active in eastern Kansas in the late 1850's. The colony existed from about 1856 to 1860, no more than three or four years, during which time it competed vigorously with Garnett for designation as county seat. Garnett won, and shortly thereafter the colony at Hyatt ceased to exist. Its leader in 1856 was W. F. M. Arny, of special interest since a "Mr. Samuel Arny" collected and sent to Kennicott, at some time before 1859, the specimens that became the holotypes of both *C. rhinomegas* Cope and *Diadophis arnyi* Kennicott. The latter is still recognized as *D. punctatus arnyi.*

According to Murphy (1972, reference and copies of pertinent pages courtesy Dorothy Licktieg), William Arny married Selina Craft in 1836, and they had three sons: Albert in 1837, Samuel in 1839, and William in 1846. Only the latter survived his parents, and Samuel was in his late teens when he sent the snakes to Kennicott that immortalized his family's name.

Actually, one other name, *Elaphe quivira* Burt (1946), has been applied to *E. g. emoryi* (s.s.), but it is a *nomen nudum,* existing in print only in the title of a presentation scheduled for the April 12, 1946, 78th annual meeting of the Kansas Academy of Science. As a frequent visitor to Kansas in those times, HMS learned that Burt intended to apply the name to one of the rare striped variants from Kansas of *E. g. emoryi,* but before doing so he realized what it was, so the description never appeared. It was undoubtedly a great disappointment to him, because he obviously had hoped initially to immortalize the name Quivira, which he had adopted for his biological supply company (Quivira Specialties Company, of Topeka, Kansas), although it would have been more for the Indian tribe of that name than for his company. As he stated (Burt, 1948), Quivira "is an old Indian name referring to villages or tribes of this Mid-West area as of some 400 to 500 years ago. Some of the ruins are said to have been found in central Kansas near Lyons and at other points and there are reports printed by the Nebraska State Historical Society indicating the probable existence of "Quivira" ruins in South-central Nebraska. By general usage Quivira, like Jayhawk, has become a synonym of Kansas; just as Cibola signifies New Mexico."

No other names previously applied to this species can be contrued as based upon *E. g. meahllmorum*, as reviewed in the following accounts. The holotype of *Coluber guttatus* Linnaeus (1766) is still in the Zoological Museum of Uppsala, Sweden, no. 147, according to Wallin (1992:226). Its original description, although brief, suffices to assure as correct the association long accepted for it and adopted most critically by Dowling (1952:2), who restricted the type locality, originally "Carolina," to Charleston, South Carolina.

An amazing eight names, aside from those now referred to *E. g. emoryi* (s.s.), were assigned by Boulenger (1894:39-40) to junior synonymy with *Coluber guttata*, and he assigned one other, *Coluber rosaceus* Cope (1888), to the synonymy of *C. laetus*.

Cope's *C. rosaceus* is the most familiar of all, because it was long recognized as a valid species or subspecies (of *E. guttata*) following Barbour (1920). Its holotype is USNM 14418, Key West, Monroe Co., Florida. It has seldom been recognized as valid since Duellman and Schwartz (1958:298-300) rejected it, although Staszko and Walls (1994: 70, 82-83) recognize it as a "weak" subspecies..

Cope (1888) also at the same time described a *C. g. sellatus* (syntypes USNM 6507 fide the original description {5507 fide Cochran, 1961: 165}, Palatka, Putnam Co., Florida, and USNM 9692, Arlington, Duval Co., Florida) that has never been recognized as valid. It was distinguished from *C. g. guttatus* on the basis of color and pattern features, as well as having 29 instead of 27 scale rows, all within the range of variation of sympatric *E. g. guttata*.

None of the other seven names applied to the species has ever been accepted as valid. The earliest, *Coluber maculatus* Bonnaterre (1790:19), was based in part on a specimen from Louisiana, and in part on Catesby's (1743) prelinnean description of the "corn snake" from Carolina, part of Linnaeus' hypodigm of *C. guttatus*. Location of the Louisiana type is unknown, although it may be in the Paris Museum. Its ventrals and caudals were given as 119 and 70, respectively; the former is no doubt a lapsus for 219. However, inasmuch as Bonnaterre explicitly attributed some (not all) ventral and caudal counts to other authorities (e. g. *Crotalus horridus* to Linnaeus and Tyson, *C. dryinus* to Linnaeus and Seba, and *C. durissus* to Linnaeus and Lacépède, two sets of counts for each), and must have done so for counts on other taxa with no explicit attribution but of which he apparently saw no specimens, it is concluded that the counts for his *C. maculatus* also were drawn from the literature, as noted, and do not in reality pertain to his specimen from Louisiana, because that specimen was described as having a whitish venter (no mention is made of any spotting), and the reddish, black-edged dorsal blotches as split along the midline, alternating on the two sides and fused to form a zigzag stripe. The reddish blotches are of regular occurrence in young *L. calligaster* (Harlan, 1827), and common in adults; and the unmarked venter and split dorsal blotches occur occasionally (Blanchard, 1921: 177-8) in that species, whereas they do not in any other species, including *E. guttata,* to which the Louisiana specimen might be referred. The ventrals and caudals of *L. c. calligaster* are 196-215 and 38-57 respectively (Blanchard, 1921: 117), much different from the supposed 219 and 70, respectively, given by Bonnaterre. As argued previously, those figures are not certainly applicable to Bonnaterre's Louisiana specimen. Because of the uncertainty of identity of Bonaterre's Louisiana specimen, and its possible representation of *L. calligaster,* we here designate, from Bonnaterre's hypodigm, the specimen on which Catesby (1743) based his description, not the specimen described by Bonnaterre, as lectotype of *Coluber maculatus* Bonnaterre (1790), in conformance with Art. 74 (c) of the Code. Thus that name definitively becomes a junior synonym of *E. g. guttata* (Linnaeus, 1766).

Eight years later Donndorff (1798: 206) named and described a *Coluber compressus,* without locality, based on a description and illustration in a 1790 work by Merrem (1790, fasc. 2: 49, pl. 11) in which no scientific names were given, although the vernacular "die zusammengedrückte Natter" was applied. Curiously, Daudin (1803: 318-321, pl. 77, fig. 2) also named the same "zusammengedrückte Natter" as *Coluber pantherinus,* reproducing Merrem's illustration and translating his description into French. Both the description and the figure are commensurate with assignment to *E. g. guttata,* of which both *C. compressus* Donndorff and *C. pantherinus* Daudin are incontestably junior synonyms. No type is known.

Shaw's (1802:460-1, 1 fig.) *Coluber carolinianus* was another name based on Catesby's prelinnean account, hence is clearly referable to *E. g. guttata.*

Coluber molossus Daudin (1803: 269-271) was based on reports by Bosc on specimens he observed in "Carolina." Presumably no types exist, although ventral and caudal counts are given on two specimens (220 and 60, 226 and 64), whether given by Bosc or taken on snakes seen by Daudin. Assignment to *E. g. guttata* is assured.

Coluber floridanus Harlan (1827: 360) was very briefly described, from "East Florida," but appears to be correctly referred to the synonymy of *E. g. guttata.* The type was stated in the original description to be in the Academy of Natural Sciences of Philadelphia, but it appears to have been lost since it is not entered in Malnate's list (1971) of the Academy types.

The remaining name, *Elaphis rubriceps* Duméril, Bibron and Duméril (1854: 270-2), was based on a specimen in the Paris Museum from an uncertain locality, thought by the authors to be in North America, probably New York. Its description agrees with variation known in *E. g. guttata.*

It is of interest to note that, as pointed out by Boulenger (1894: 40), Jan and Sordelli (1867: livr. 24, pl. 2) illustrated under the name *Elaphis alleghaniensis* (Holbrook, 1836) not only an *Elaphe obsoleta* (Say, 1823), of which Holbrook's name is a junior synonym, but also *E. g. guttata.*

Phylogeny

Character-state dispersal in *E. guttata* leads the authors to hypothesize that *E. g. meahllmorum* is ancestral to the other two subspecies. In the course of evolution *E. g. guttata* retained the ancestral large and few dorsal blotches, but became reddish, whereas *E. g. emoryi* retained the ancestral gray color but experienced a marked increase in number of dorsal blotches.

All three subspecies of *E. guttata* now have isolated, northern relictual populations, none of which have evolved taxonomic distinction. As many as five dichopatric populations of *E. g. guttata* exist north of the main body of the subspecies' population (Conant and Collins, 1991: map 167). One widely disjunct population of *E. g. emoryi* exists in central eastern Utah and central western Colorado (Fig. 1). At least one and possibly two apparently disjunct populations of *E. g. meahllmorum* exist northeast of its main body, in (1) eastern Texas, western Louisiana and southern Arkansas, and (2) eastern Oklahoma, northwestern Arkansas and southern Missouri.

These several relictual populations collectively suggest a wider distribution of the species to the north in the past, during a hypsithermal period, and a partial withdrawal during the current hypothermal period, occurring not long enough ago to have permitted subsequent taxonomic differentiation.

Roth et al. (1989) hypothesized that the isolated population of *Heterodon n. nasicus* in northwestern Colorado arrived there via the Wyoming Corridor between the northern and southern Rocky Mountains during the early Holocene Climatic Optimum some 8500-5000 years ago. Probably the West Slope population of *E. g. emoryi* arrived there by the same route at the same time, when the entire species was more widely distributed than now. Bury's (1983) record from extreme northeastern Utah provides support for the hypothesis of northern, not southern, derivation of the West Slope population.

Both *E. g. emoryi* and *E. g. meahllmorum* are conspicuously partial, throughout most if not all of their ranges, to the vicinity of water, either lentic or lotic, and are not to be found distant from it. This strong affinity could well have been an isolating factor in some historic stage of xeric hypsithermy, affecting the relationships of all three currently recognized subspecies.

The exclusively northern relic populations suggest a late Holocene hypothermal period as being responsible for the range retraction that all three subspecies now exhibit. The southward confinement of *E. g. guttata* encountered no obstacle in the form of differentiated populations of its own species, unless the Keys population was then in existence. On the contrary, a southward retreat of *E. g. emoryi* did encounter *E. g. meahllmorum*, and the extensive interdigitation of the ranges of these two taxa, and the apparent isolation of two northern enclaves from the body of the latter subspecies, are very likely the result of that retreat.

Those phenomena also suggest that the two western subspecies evolved in dichopatry, *E. g. emoryi* to the northwest, *E. g. meahllmorum* retaining its position to the southeast. Their response to each other in renewed contact is typical of secondary subspecies.

Intergradation

No intergradation between *E. g. guttata* and its nearest relative, *E. g. meahllmorum*, is known to take place at the present time (Dundee and Rossman, 1989), although certainly, as shown by their pl. 16, the latter subspecies in Louisiana is distinctly less gray than elsewhere. A relatively recent contact is indicated, but none appears to exist now.

On the other hand, intergradation almost certainly occurs between the two western subspecies in scattered areas of contact, but their integrity is surprisingly well maintained in other areas. For instance, in El Paso Co., Texas, the dorsal body blotch counts of 39.5, 40, 40.5, 42 and 54 occur; all are readily assignable to one subspecies or the other, the latter to *E. g. emoryi*. On that basis, however, occurrence of *E. g. emoryi* in adjacent Chihuahua, not now known, is to be expected. Indeed, the northernmost specimen from Chihuahua (BYU 13918, Casas Grandes) has the highest number (44.5) of dorsal blotches of all 57 specimens seen from Mexico, except for two (KU 67653, 37 mi S Matehuala, San Luis Potosí, with 46.5 blotches; and UTA 4856, 10 mi S Cd. Mante, Tamaulipas, with 44.5 blotches), some of whose blotches are secondarily divided transversely; they are consequently not comparable with others without such secondarily subdivided blotches.

In 29 specimens from New Mexico, all have 45.5-65 dorsal blotches except for three. One, with 42 blotches (UNM 7501, 1.5 mi SW Pilar, Taos Co, Hy 64) was rejected as a probable released or escaped pet, inasmuch as all others from nearby areas had typically numerous blotches. Inasmuch as this species is extremely popular as a pet, a number of distributional discrepancies may be due to escapes or releases in exotic (from original sources) localities. Another New Mexico specimen, with 43 blotches (UNM 13195, Bottomless Lakes, Chaves Co.), may similarly have been imported, because six other specimens from the same or adjacent localities in Chaves Co. had 46.5-56.5 (mean 50.25) blotches. The specimen from New Mexico referred to *E. g. meahllmorum* has 44 dorsal blotches, and is from Del Rio Ditch, 0.2 mi E Hy 28, Dona Ana Co. (NMSU 3136). Others from the same county (one from the same locality as NMSU 3136) have 48, 48.5 and 50 dorsal blotches, hence are clearly referable to *E. g. emoryi.* Since both subspecies occur in nearby El Paso Co., however, both may well also occur in adjacent Dona Ana Co. On the other hand, this general area may be one of intergradation; sufficient series are not yet available to resolve the question definitively.

Another area of possible intergradation is the vicinity of the Davis Mts. in Jeff Davis and Reeves counties, Texas, where counts of 43, 45.5, 48.5, 53 and 53 are available; the first is assigned to *E. g. meahllmorum,* the others to *E. g. emoryi.* The two counts from Pecos Co. (45.5, 47.5) are clearly exemplary of the latter subspecies, as is the count of 50 for the holotype of the subspecies from nearby Crockett Co. (Baird and Girard, 1853: 157), and the count of 46.5 for one from Tom Green Co. (KU 81987, 4 mi NW Christoval). However, one from Coke Co. (KU 81984, 6 mi N Water Valley) has but 42 blotches, and one from Irion Co. (KU 81985, 2 mi W Mertzon) has 44.5; these hence fall with *E. g. meahllmorum,* ranging northward from the Val Verde-Terrell counties area, where the counts are 36, 36.5, 37, 37.5, 39, 41, 42, 43, and 44 (mean 39.6). Even there, one count of 47 occurs (UCM 56667, 6.7 mi N Comstock), but it in turn fits geographically with the large southward extension of *E. g. emoryi* that circumscribes the Edwards Plateau (Bandera Co., 50; Bastrop, 46; Brown, 49; Callahan, 45; Coleman, 47; Frio, 49.5; Taylor, 47.5). These counts are too consistently referable to *E. g. emoryi,* without exception, to regard them as meaningless or intergrades.

A Brown Co. count of 44 (UTA 16759, Hy 377 100 m N Hy 1176) is consistent geographically with the extensive distribution of *E. g. meahllmorum* in eastern Texas, the nearest records being for Eastland Co. (43, 43.5) and Erath Co. (44, 44.5).

One other from Eastland Co. (KU 1139, nr Cisco) has 45 blotches and is assigned to *E. g. emoryi*; the other two (KU 1054, 1809), here assigned to *E. g. meahllmorum,* are also from Cisco (not "near").

To the northwest, the Stonewall (42), Knox (44) and Throckmorton (44) county records justify extension for *E. g. meahllmorum* into that area; one *E. g. emoryi* with 52.5 dorsal body blotches (UTA 482, 20 mi S Throckmorton) is, however, from the same locality as the specimen referred to the other subspecies. Intergradation in that area may well occur.

There are only three other specimens on the basis of which the range of *E. g. meahllmorum* is depicted on our map to extend into northern central Texas. One is from Wise Co., with 44 blotches (UTA 16338, LBJ Natural Grassland); others from that county, including another from the same locality with 62 blotches, have 52.5 (2) and 57.5 blotches. The other two, with 44 and 44.5 blotches, are from Dallas Co. (UTA 26462, S Cedar Hill, jct Texas Plume Rd & Lakeridge Rd; UTA 30226, Texas Plume Rd, 0.6 mi W Anderson Rd); others from the same and adjacent counties (Hood, Johnson, Palo Pinto, Parker, Shackelford, Tarrant) all have *E. g. emoryi* counts (45.5, 46, 47.5(2), 48, 48.5(3), 49(2), 50, 50.5, 51.5, 52, 52.5, 53, 56.5, 59; mean 50.2).

In Oklahoma, the only unexpected record is of an *E. g. emoryi* with 48.5 blotches from Le Flore Co. (UO field 3212; Holson Valley Rd, 0.5 mi S Cedar Lake), whereas others from that county have 35.5, 36, 39, 40 blotches, consistent with *E. g. meahllmorum*. The exceptional specimen may, or may not, be an import; intergradation is not evident. It is of interest that the highest blotch count ever recorded for the species (73) occurs on a specimen from Cimarron Co., Oklahoma (UO 33993, 1.5 mi E Kenton).

In Missouri, four specimens of *E. g. emoryi* are from surprisingly far south and east: KU 81980-1, McDonald Co., Noel, with 50.5 and 54 blotches; KU 81983, Taney Co., Kissee Mills, with 48.5 blotches; and UCM uncat., Crawford Co., 6 rd mi E Steelville, with 48 blotches. Yet KU 19093 from 1 mi N Branson, Taney Co., has 39.5. The two taxa may be sympatric in these areas.

The preceding analysis leaves no *E. g. meahllmorum* with 45 or more dorsal blotches on the body. On the contrary, 251 of 257 *E. g. emoryi* (98%) have 45 or more. Of the six exceptions, one is from Nebraska (KU 52221, Jefferson Co., 4 mi S, 0.5 mi W Reynolds, with 44), one from New Mexico (UNM 13195, Chaves Co., Bottomless Lakes State Park, with 43), one from Texas (WTAM 6078, Potter Co., Lake Meredith, with 43), and the other three from Kansas (KU 1058, Anderson Co., with 39.5; KU 206488, Greenwood Co., T28S, R12E, Sec. 3, with 43; and KU 158009, Marion Co., Marion Co. State Lake, with 43.5). How many, if any, of these exceptions may be due to importation is conjectural.

The over-all picture of the contacts between *E. g. emoryi* and *E. g. meahllmorum* is of possible sympatry in some areas (especially in Missouri, and possibly in Oklahoma), parapatry in others, and probable intergradation in others. More material will be required to establish definitively what the interaction is in any given area. Extensive range interdigitation in Texas is clearly evident, but to what extent, if any, it is artifactual remains to be clarified. It will be of much interest to determine whether the area where the species appears to be absent in southeastern coastal Texas (see Fig. 1) contacts the range of *E. g. emoryi,* thus isolating the population of *E. g. meahllmorum* in eastern Texas, western Louisiana and southern central Arkansas. Also much to be desired is confirmation of the isolation of that subspecies in southeastern Oklahoma, northwestern Arkansas and southern Missouri. That the three isolated enclaves of *E. g. meahllmorum* may differ in their interaction with *E. g. emoryi,* where their ranges are in contact, is not likely.

Taxonomic Ranks

Because *E. g. guttata,* as the authors understand it, now has no contact with the other two subspecies, its taxonomic rank is not established by the Biological Species Concept, which is limited in application to sympatric and possibly also to parapatric populations. The Evolutionary Species Concept does apply in such cases of allopatry, however, although with considerable subjectivity in determining whether or not an allopatric population in sufficiently differentiated to be regarded as having established a unique evolutionary trajectory. In the case of *E. g. guttata,* its reddish coloration is indeed distinctive, at least in degree, as compared with the other subspecies, and possibly the distinction may only become firmly established and even significantly supplemented in the future, but the subspecies' similarity to and apparent origin from adjacent *E. g. meahllmorum* in Louisiana (see especially Dundee and Rossman, 1989: pl. 16) convinces the authors that under the Evolutionary Species Concept *E. g. guttata* is best retained at a subspecific rank. The descriptions of Louisiana specimens (Raymond and Hardy, 1983) of what the authors now know to be *E. g. meahllmorum,* with pink in their coloration, bespeaks incomplete differentiation. So also does the occurrence in *E. g. guttata* (Schnitzler, 1990: 161) of the same, curious, light transverse areas across the dorsal body blotches as occurs regularly in southeastern *E. g. meahllmorum,* often splitting the blotches. There are too many shared peculiarities of these two populations, especially where their ranges are approximated, to regard them as safely launched on separate evolutionary tangents.

That they may be regarded as secondary subspecies, as suggested by Raymond and Hardy (1983), however, is a tenable hypothesis, perhaps presupposing an even more extensive range retraction having occurred at some time in the past than at present.

Despite the considerable evidence of possible sympatry of the other two subspecies in some (especially northeastern) areas of contact, the high probability of interbreeding (hence intergradation) elsewhere likewise imposes a subspecific, not specific, ranking as the most parsimonious assumption at the present time. Only with explicit evidence of sympatry, inviolate parapatry or dichopatry *throughout* the areas of juxtaposition of ranges, with or without hybridization, would assumption of specific rank be justified. As argued elsewhere, these two subspecies, as well as *E. g. guttata*, appear to be secondary.

The apparent phylogeny of these three taxa is also more harmonious with the concept of one species with three subspecies than with that of two or three separate species.

Descriptions in the literature of southern Florida populations frequently referred in the past to *E. g. rosacea* suggest that a reappraisal is in order, particularly in view of the separation of *E. g. meahllmorum*.

SPECIMENS EXAMINED (410)

(counties in italics)

1. *Elaphe guttata emoryi* (252)

COLORADO (UCM; 38). *Baca*: Pritchett (56055); SE Pritchett (14968); SW Pritchett (52057). *Bent*: John Martin Reservoir (15233). *Delta*: Delta (field 4950); Eckert (56187, 56189, 56193-4, 56200-1, 56219, field 4951); 2 mi E Fruit Growers' Res. (56214); Hart's Basin (field 4944, 4947, 4949); Orchard City (56566, field 4999); Redlands Mesa (56212). *Garfield*: Rifle (19712). *Las Animas*: Cottonwood Creek (7643); SW Pritchett (9734). *Mesa*: Colorado National Monument (18108); Fruita Canyon (23948); Gateway (6700); Grand Junction (18109, 31468-9); Molina (56215). *Montrose*: Escalante Canyon (50713); Nucla (10700). *Otero*: La Junta (51876). *Prowers*: Lamar (1226). *Pueblo*: Lime (31466); Pueblo (2669-70, 31467).

KANSAS (KU except as noted; 103). *No county*: Flint Hills (OMNH 34313). *Anderson* (1057-8): 4 mi N Garnett (30072). *Barber*: 1 mi W Aetna (20005); 15.2 km W Medicine Lodge (204056); 5 mi S Sun City (19200); 7 mi S Sun City (18112). *Bourbon*: 6.4 mi W, 0.6 mi S Garland (192204). *Butler*: T25S, R6E, Sec. 25 (~2 mi NE El Dorado; 206489); T27S, R6E, Sec. 33 (~3 mi S Leon; 192411). *Chase* (188697): 17.6 km SE Bazaar (188690); 6.4 km E Cottonwood Falls (188698); 1.6 km S Saffordville (188694); 8 km S Saffordville (188686-9, 188693, 188695); 8 mi S Saffordville (75165); 3.2 km NE Strong City (188696). *Clark*: Clark Co. State Lake (21388, 207290). *Clay*: T10S, R4E, Sec. 29 (Milford Lake area; 218764). *Cloud:* 4.8 km N Glasco (206308); 8 km S Jamestown (207168). *Comanche* (1059): 4 mi W Aetna (18156). *Cowley*: 35.5 mi W Cedarvale, Hy 160 (176712); T35S, R5E, Sec. 20 (~Silverdale; 206173); Winfield (29983). *Dickinson*: T3S, R4E, Sec. 8 (~SE corner; 192106). *Douglas* (1073): Apponoose Creek (1063); Clinton (BYU 9138); 4 mi S

Clinton (188701); 7.5 mi NE Lawrence courthouse (28679); Washington Creek (1077-8). *Elk*: 6.4 km S Fall River (193220). *Ellis*: Hays (16554-5); 4 mi E, 2 mi N Hays (159779). *Ellsworth*: 9.6 km E Lorraine (179026). *Ford*: 3.2 km S Hodgeman Co. line, Hy 283 (182289). *Franklin* (55377-8). *Geary*: Hy 177 5 mi S I70 (159778); Hy 177 8 mi S I70 (171162); T13S, R8E, Sec. 10 (~5 mi N Dwight; 159777). *Gove*: T15S, R26W, Sec. 12 (SE corner; 216123). *Graham*: 5.6 km S Bogue (192201-2). *Greenwood*: T28S, R12E, Sec. 3 (~1/2 way between Severy and Fall River; 206488). *Hodgeman*: Hodgeman Co. State Lake (182289); 14.4 km SW Jetmore (206309). *Jewell*: Jewell Co. State Lake (158019). *Lane*: T18S, R27W, Sec. 2 (~Alamota; 217222). *Leavenworth*: 7 mi NE Lawrence (2425). *Lincoln*: Wilson dam (174553). *Linn*: Cadmus (192203); 6.4 km SE Centerville (207170). *Logan*: T14S, R33W, Sec. 2 (~10 mi NW Elkader; 217224). *Lyon*: ESU Ross Nat. Hist. Reservation (192376). *Marion*: Marion Co. State Lake (158009). *Marshall*: T4S, R7E, Sec. 16 (~4 mi N Blue Rapids; 207291). *Meade*: SE corner (22842). *Mitchell*: 5.6 km WSW Beloit (206310). *Montgomery*: 4 mi W Sycamore (154029, 154514). *Morris*: 16 km S Council Grove (188692), *Ness*: T16S, R22W, Sec. 33 (~Brownell; 216189), *Norton*: T4S, R21W, Sec. 35 (~5 mi N Densmore; 217223). *Osage*: 0.8 km N Melvern (188699); Quenemo (1053). *Osborne*: T10S, R15W, Sec. 18 (SW corner; 216122). *Ottawa*: NW corner (188700); SW Ada (17033); 8 km W Delphos (207169). *Pottawatomie*: 6.5 mi N, 1.5 mi E Olsburg (49361). *Republic*: 8 km S Belleville (206311, 207167). *Riley* (55376): Hy 177 just N I70 (207189); 0.25 m W end Tuttle Creek dam (49360); Winkler (17094). *Russell*: 17.6 km SW Lucas (188702). *Saline*: T14S, R5W, Sec. 5, NNW Brookville (UTA 10934); 1.6 km S, 1.6 km E Salina (182318-9). *Shawnee*: T12S, R14E, Sec. 10 (~3 mi SE Valencia; 207289). *Smith*: T5S, R15W, Sec. 17 (~Claudell; 203310). *Trego* (1472,2426-8): Cedar Bluffs Lake (191951); 1.6 km E Cedar Bluff dam (182320). *Wabaunsee*: 1 mi SW Alma (159824). *Wilson*: 4.8 km E Buffalo (188691). *Woodson*: Toronto Point, Toronto Lake (170627).

MISSOURI (KU except as noted; 8). *Atchison*: 1 mi N Rockport (81976). *Bates*: Drexel (81982). *Cass*: 0.5 mi NE Drexel (81978). *Crawford*: 6 rd mi E Steelville (UMC uncat.). *Hickory*: 5 mi SE Cross Timbers (81979). *Jackson*: 4 mi S Blue Springs (81975). *McDonald*: Noel (81980-1). *Taney*: 6 mi NE Kissee Mills (81983).

NEBRASKA (KU;2). *Gage*: Barneston (52222). *Jefferson*: 4 mi S, 0.5 mi W Reynolds (52221).

NEW MEXICO(UNM except as noted; 27). *Bernalillo*: 2 mi N San Antonito, Hy 14 (36910); Embudo Canyon, 10 mi E Albuquerque (4745); Hy 14 1 mi N I40, Sandia Mts. (32896); Pino Canyon, Sandia Mts. (415); 1 mi W Tijeras post office (48749); nr Tijeras Canyon, La Mura Rd (36574). *Chaves*: Bottomless Lakes State Park (13195, 16467, 17227); E side Mirror Lake, Bottomless Lakes State Park (15055, 15129); 7 mi E Roswell, Hy 380 (14589); Hy 380 at Rio Hondo, E Roswell (36943). *Dona Ana*: Del Rio Ditch 0.2 mi E Hy 28 (NMSU 3135); East Picacho School, Las Cruces (NMSU 2740); 3 mi NW Las Cruces, Hy 292 (NMSU 4959). *Eddy*: Black River, 4 mi NE Black River Village (43669); T25S, R24E, Sec. 35 (~7 mi SW Whites City; 54828); Cottonwood Spring, Cottonwood Draw, T25S, R25E, Sec. 36, SW 1/4 (~5 mi S Whites City; 51986); Dark Canyon Rd, T23S, R23E, Sec. 14, 4100' (49056); Hy 31, 0.5 mi W Pecos River, nr Carlsbad (19372). *Guadelupe*: Puerto de Luna, Hy 3 (36909). *Quay*: Logan, 3800' (31664). *Sandoval*: Placitas Fish Hatchery, N Sandia Mts (18275). *San Miguel*: 9.5 mi W Tucumcari, Hy (16629). *Santa Fe*: 2 mi S Madrid, Hy 14 (48072). *Union*: Dry Cimarron River, Folsom Falls (52022).

OKLAHOMA (UO except as noted; 20). *Alfalfa*: 7 mi N Jet (25291). *Beaver*: nr Gate (13742). *Blaine*: 20 mi SW Okeene (8454); 4 mi N Watonga (29266). *Cimarron*: 1.5 mi E Kenton (33993). *Comanche*: 0.5 mi SW Mt Quanah, Ft. Sill Military Res. (field 2295); Lake Lawtonka (12901); E Lake Lawtonka (12900); W Cache Creek (8137, 8213); Wichita Mt. Game Refuge (26889). *Garvin*: Pauls Valley (8860). *Greer*: 1.7 mi S Salt Fork Red River (25825). *Harmon*: NW Reed (29278). *Kay*: 3 mi N, 5 mi E Ponca City (25976). *Kiowa*: 10 mi NW Meers (13187). *Le Flore*: 0.5 mi S Cedar Lake, Holson Valley Rd (field 3212). *Major*: E Glass Mts (22890). *Roger Mills* (26438). *Seminole*: Bowlegs (10289).

TEXAS (UTA except as noted; 53). *Bandera*: Hy P 37 0.5 mi NE Hy 1283, 13 air km W San Geronimo, 350 m (UTEP 8988). *Bastrop*: 100 m S of Hy 969, 2.4 km SE Hy 1704 (15810). *Brown*: Hy 279, Brownwood State Park (WTAM field DC 92-R22). *Callahan*: I20, 1.5 m E Hy 2228 (5261). *Coleman*: 10 mi SE Santa Anna, Hy 1176 (5064). *Cooke*: Gainsville (KU 13726). *Dallas*: Duncanville, Greenhills Environmental Center (14097); E Mt. Creek Lake (2126); Plume Rd at Lakeridge Rd, S Cedar Hill (26463). *Denton*: Keller (22271). *Eastland*: nr Cisco (KU 1139). *El Paso*: 1 mi E Clint, exit to I10 (UTEP 124). *Foard*: 5 mi N Crowell, Hy 6 (9295). *Frio*: 8 km W Derby (22272). *Hall*: 2 mi SW Klondike (30678). *Hansford*: Gibbner Ranch, 10 mi N Spearman, Hy 760 (WTAM 5004). *Hardeman*: 3 mi N Copper Breaks State Park, Hy 6 (9293). *Hood*: Benbrook-Aledo Rd at Hy 2376 (11148); Hy 171 at Hy 377 (14228); Hy 179, 2.5 km NW Hy 377 (11149). *Hutchinson*: 2 mi N Stinnett (WTAM 5979). *Jeff Davis*: 41.6 km N Ft. Davis (KU 187741); Limpia Canyon, 5 mi NNW Ft. Davis (KU 45355). *Johnson*: I35, 0.6 mi SE Hy 917, 7.9 mi SE Tarrant Co. line (2614). *Lubbock* (5535). *Palo Pinto*: 7 mi W Graford (30680); 4 mi N Palo Pinto (2072). *Parker*: Aledo (266); 1 mi E Aledo (2125); 8.2 mi SE Weatherford (EAL 2317). *Pecos* (UTEP 14715): Ft. Stockton (KU 174798); 20 mi E Ft. Stockton (KU 81986). *Potter*: 6 mi W Amarillo (2058); Lake Meredith (WTAM

6078). *Randall*: 0.75 mi E Canyon, Hy 217 (WTAM 8379). *Reeves*: Hy 17, 4.2 km S Hy 290 (28891); 1 mi S Toyahvale, Hy 17 (UTEP 6119). *Shackelford*: 6.6 mi N Albany, Hy 293 (2057); 16 km W Albany, Hy 351 (14075). *Tarrant*: Benbrook-Aledo Rd (11368); Hy 1187, 1 mi W Hy 1902 (2912); Mary's Creek, 200 yds W jct Ridgmar Blvd and Dakae St. (1156). *Taylor*: Camp Berkeley (BYU 6060). *Throckmorton*: 20 mi S Throckmorton (UTA 482). *Tom Green*: 4 mi NW Cristoval (KU 81987). *Val Verde*: 6.7 mi N Comstock (UMC 56667). *Wise* (30677): 4 mi NNW Decatur (8639); 6.4-8 km N Decatur, off Hy 287 (15312); LBJ National Grassland (16337). *Young*: 1.3 mi E Graham, Hy 380 (9437).

UTAH (1). Grand: Moab (BYU 18896).

2. *Elaphe guttata meahllmorum* (157)

ARKANSAS (12). *Cleburne*: Big Creek Natural Area MPM (19100); Big Creek, 5 mi N Pickens (MPM 17000); W Pangburn (MPM 15703). *Garland*: Montgomery Co. line (ASUMZ 6221). *Marion*: Promised Land Ridge, Bull Shoals Lake (MPM 20306). *Montgomery*: 3 mi W Albert Pike, Hy 106 (ASUMZ 18478). *Polk*: Ouachita National Forest, Hy 88, 19 km E Oklahoma border (UTA 12717). *Pulaski*: Murray Park, Little Rock (ASUMZ 7823). *Saline*: Rattlesnake Mt. (ASUMZ 18304). *Washington*: Devil's Den State Park, 6 mi WNW Winslow (ARK 68-735-1833). *White* (MPM 18641).

ILLINOIS (2). *Monroe*: Bluff Rd, 7 mi N Valmeyer (UIMNH 50963); Fults (UIMNH 50837).

MISSOURI (KU except as noted; 4). *Cedar*: El Dorado Springs (81977). *Greene*: Hy 123 W Harold (UNM 10089). *McDonald*: 2.4 mi NE Noel (30030). *Taney*: 1 mi N Branson (19093).

NEW MEXICO(1). *Dona Ana*: Del Rio Ditch, 0.2 mi E Hy 28 (NMSU 3136).

OKLAHOMA (UTA except as noted; 6). *Delaware*: 8 mi S, 1.4 km W Jay (KU 154481). *Le Flore*: Cedar Lake, Holson Valley Rd (OMNH field 3215); Ouachita National Forest, Ark. Hy 1 (22270); Rich Mt. Crest, Hy 1, 13 km W Arkansas line (26118); 3.2 km S Zoe, Hy 259, 3.2 km N Hy 1 (10933). *McCurtain*: Hy 259, 0.6 km S Boktukolo Creek, 15.3 km S Le Flore Co. line (26461).

TEXAS (UTA except as noted; 76). *Anderson*: Hy 860, 0.6 km N Hy 2330 (16928); Pert, Hy 155, 5.5 km S Hy 2267 (16807). *Aransas*: 2.8 mi N Lamar (EAL 512). *Atascosa*: Benton (KU 8438). *Bexar*: San Antonio (KU 13779). *Brazos*: 5 mi NE College Station, Elmo Weedon Rd, 1 mi N Hy 30 (UTEP 10486); Hy 30, 8.2 mi E Hy 168 (UCM 41824). *Brown*: Hy 377, 100 m N Hy 1176 (16759). *Cameron*: Bayview, General Store Hy 2480, 0.6 km S Hy 510 (26699); Bayview, Hy 2480, 100 m S Hy 510 (26698); Brownsville (UCM 15234); Hy 77, 2 mi NW El Camino Real (8389); Los Fresnos (UCM 15232); Los Fresnos, downtown, Hy 1847

(8391, 8402); Hy 510, 1 mi W Hy 1847 (8404). *Coke*: 6 mi N Water Valley (KU 81984). *Dallas*: Texas Plume Rd, 0.6 mi W Anderson Rd (30226); Texas Plume Rd and Lakeridge Rd, S Cedar Hill (26462). *Duval*: Hy 16, 13.2 km S McMullen Co. line (17179). *Eastland*: Cisco (KU 1054, 1809). *El Paso*: Auburn Drive, Ascarate Park area, El Paso (UTEP 13784); 416 Lisbon St., SE El Paso (UTEP 9989); Hys 20 and 793, 4.8 mi SE Fabens (UTEP 12339); Upper Valley nr Canutillo, Gato Rd off Doniphan St. (UTEP 3562). *Erath*: Cedar Point, 1.6 km W jct Hys 2157, 3106 (14731-2). *Irion*: 2 mi W Mertzon (KU 81985). *Jeff Davis*: 5 mi S Toyahvale, Hy 17 (UNM 35798). *Jim Hogg*: 6.4 km SW Hebbronville (KU 174799); 18.8 mi SW Hebbronville (10439). *Jim Wells*: 14 mi S Alice, Hys 141, 281 (UTEP 5955). *Karnes*: 5.6 mi N Choate, Hy 239 (WTAM 8766). *Kenedy*: 8 mi N Armstrong, Hy 77 (EAL 2374); 19.1 mi S Riviera (EAL 520); 26.2 mi S Riviera (EAL 731); 34.5 mi S Riviera (EAL 732). *Kleberg*: 4.5 mi W Riviera (EAL 3918). *Knox*: Hy 6, 19 km N or S Benjamin (14078). *La Salle*: Hy 624, 41.5 km W Hy 16 (16664); Hy 624, 21.9 km W La Salle Co. line (16780); Nueces River nr Cotulla (KU 13780-1). *McMullen*: 16.7 mi N Freer, Hy 16 (10428); Hy 624, Nueces River (16662); Hy 16, 3.7 km N Hy 624 (16691); Hy 16, 11.1 km S Hy 72 (18499); Hy 624, 15.4 km W Hy 16 (16806); Hy 624, 23.3 km W Hy 16 (16663). *Nueces*: 3.5 mi W Chapman Ranch (KU 61001). *Presidio*: 38.1 km W Lajitas, Hy 170 (14629). *Refugio* (UTEP 14031). *San Patricio*: 1.9 mi S Odem (EAL 255). *Starr*: Rd on S border of Federal Property, behind Falcon Dam (17784); Rio Grande City (KU 8439); Hy 83, 5.6 km W Hy 755 (14733). *Stonewall*: Hy 380, 4.3 mi W Hy 83 (2903). *Terrell*: 1 mi W Pecos River (KU 45354). *Throckmorton*: 20 mi S Throckmorton (481). *Val Verde*: 3 mi SE Comstock (KU 129721); 3.2 km N Comstock, Hy 163 (10931); 8 km N Comstock, Hy 163 (10932); 6.7 mi N Comstock (UCM 56666); Hy 163, Juno rd (KU 174941); Hy 163, Baker's Crossing (KU 174942); Langtry (UNM 53328); Evans Creek, 1325 ft, Hy 90, 5.3 mi NNW spur 349 to Amistad Dam (UTEP 9157). *Van Zandt*: I20, 66 km E Dallas (15809). *Webb*: 10 mi W Bruni, Hy 359 (10339); Hy 59 betw. Laredo and Hy 2050 (10338); Hy 649, 12.4 km N Hy 3073 (19312); Hy 2050 17.3 mi S Hy 59 (KU 145867). *Wise*: LBJ Natural Grassland (16338).

CHIHUAHUA (6). 0.7 mi E Aldama Pemex, Hy 16 (UNM 34310); Casas Grandes (BYU 13918); 2 km E Gral. Trias, Hy 16 (UNM 34308); 9.2 km E Gral. Trias, Hy 16 (UNM 34309); 32 km E Gral. Trias, Hy 16 (UNM 34311); 16.1 mi S Jimenez (EAL 2535).

COAHUILA (9). 9 mi N, 5 mi W Castillón (KU 33872); 6 mi W Cuatro Ciénagas (KU 47100); 6.9 mi S Cuatro Ciénagas (EAL 2420); 30 mi N Monclova (EAL 7); 10.5 mi S Nueva Rosita (EAL 2387); 9.4 mi E Paila (UTEP 3797); 11.8 mi S Sabinas Cachuila (EAL 2391); 7.8 mi W

Sacramento (EAL 2623); Santa Cruz, 3250 ft, Hy 57 47 km N Saltillo (UTEP 6336).

DURANGO (2). 7 mi N Donato Guerra (EAL 2704); 2.6 mi S San Juan del Río (EAL 2705).

NUEVO LEON (12). 8 km NW Allende, Hy 85 (UTA 16126); Aramberri, 3600 ft. (KU 87743); 2.6 mi SW China (UTA 3386); 0.6 mi N Ciénaga de Flores (EAL 2603); García (UCM 47378); 23.8 mi NE Gral. Bravo (EAL 1187); 8 mi N Royal Courts, Monterrey (UO 33466); Sabinas Hidalgo (EAL 669, UTA 12282); 7.9 mi W Sabinas Hidalgo (EAL 4250); 17 mi S Sabinas Hidalgo, 1350 ft (KU 67650); Hy 54, 7 mi SW Hy 23 (UNM 37745).

QUERETARO (2). Hy 120, 2 km S Peñamiller turnoff (UTA 16127); Old Mill at Hda. San Nicolas Conca (Sharpton's Finca), 10.4 mi S Arroyo Seco (UTEP 9116).

SAN LUIS POTOSI (8). 20.1 mi S Antiguo Morelos (EAL 323); El Salto (UCM 46009); 19 mi S Matehuala, 4700 ft (KU 67651-2); 37 mi S Matehuala, 4650 ft (KU 67653); 39 mi S Matehuala, 5000 ft (KU 67654); 30 mi N Valles, Hy 85 (UTA 4674); 17 mi NE Villa Hidalgo, 5000 ft (KU 67655).

TAMAULIPAS (18). 6 mi N, 6 mi W Altamira (KU 33995); 3 mi S Cd. Victoria (KU 61002); 6 mi S Cd. Victoria (KU 61004); 9 mi S Cd. Victoria (KU 61003); 15.3 mi S Cd. Victoria (EAL 535); 19.1 mi S Cd. Victoria (EAL 536); 26.7 mi S Cd. Victoria (UTA 2457); 36 km S Cd. Victoria, Hy 85 (KU 140057); 39.1 mi S Cd. Victoria (EAL 537); 8 mi W González, Hy 80 (UTA 4855); 10 mi S Mante (UTA 4856); 9 mi S Matamoros (KU 61008); 10 mi SSW Matamoros (KU 61007); 12 mi S Reynosa (UCM 50118); 9 mi S San Fernando (KU 61009); 17 mi NE Santa Teresa (KU 61005); 22 mi NE Santa Teresa (KU 51006); 29 mi S Soto La Marina (UTEP 5100).

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GENERAL NOTES

NOTES ON THE BIOLOGY AND OCCURRENCE OF *ASTYANAX MEXICANUS* (CHARACIDAE, TELEOSTEI) IN SOUTHEAST TEXAS

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The Mexican tetra, *Astyanax mexicanus* (Fillipi) (Committee on Names of Fishes, 1991), or *A. fasciatus* depending upon final systematic analysis (Miller and Smith, 1986), is a Middle American species whose northern most natural distribution extends into southern Texas. *Astyanax mexicanus* originally was restricted to the Rio Grande-Pecos River drainage basin and the Nueces River drainage basin in Texas (Evermann and Kendall, 1894; Jordan and Evermann, 1896; Brown, 1953; Knapp, 1953). However, isolated populations of *A. mexicanus* have been introduced to other parts of Texas and adjacent states (Birkhead, 1980). Introduced Texas populations, identified in the literature, are found throughout the Edwards Plateau and in the Red River drainage above Denton (Birkhead, 1980), as well as all of the drainage basins from San Antonio Bay to Galveston Bay (Conner and Suttkus, 1986). The species has been so widely introduced that Hubbs et al. (1991) consider it to be distributed statewide. However, there are no records of *A. mexicanus* in the Sabine Lake drainage basin in southeast Texas.

Since 1967, *A. mexicanus* has been observed and collected in large numbers in the Hildebrandt Bayou drainage system in Jefferson County, Texas. Hildebrandt Bayou is the largest tributary of Taylor Bayou and is in the Neches Trinity Coastal Basin (Texas Water Commission, 1990). The drainage system, which starts out as a series of ditches and canals, drains agricultural and pasture lands and the southern and western portions of the City of Beaumont before joining Taylor Bayou, which historically flowed into Sabine Lake, but now flows into the Intercoastal Canal. *Astyanax mexicanus* is common in the ditches and canals as well as the upper portion of the main channel of Hildebrandt Bayou. In the area around Beaumont, *A. mexicanus* has been collected from both concrete lined and mud bottomed ditches with or without dense vegetation. The nearest natural populations are 462 km to the southwest in the Nueces River drainage (Conner and Suttkus, 1986). The most likely means of introduction into the Hildebrandt Bayou system were either through releases by aquarium enthusiasts or through bait releases (Brown, 1953).

Some of the drainage ditches on the south side of Beaumont are fed by large storm sewers which drain excess water off city streets. Large numbers of *A. mexicanus* often occupy the area immediately inside the storm sewers, especially in the winter. Populations of *A. fasciatus* in Central America behave in a similar manner, occupying the mouths of caves and springs feeding the creeks and rivers they inhabit (Romero, 1984, 1985). These subterranean habitats are used as refuges from predators and as points from which foraging forays are run to surface waters. While the storm sewers in Beaumont may serve similar purposes for foraging and predator avoidance, during the winter it is very likely that they act as warm water refuges.

In the small drainage ditches that feed Hildebrandt Bayou and drain the storm sewers, *A. mexicanus* is frequently caught singularly or in small numbers. However, in the larger, concrete drainage canals hundreds to thousands of individuals can be collected in a single seine haul. In January, 1974, the water temperature in Hildebrandt Bayou dropped to 8.0 C (Harrel and Duplechin, 1976) and resulted in the deaths of thousands of *A. mexicanus* in the main channel of Hildebrandt Bayou. At this time *A. mexicanus* was the only species observed floating dead on the water surface. However, specimens have been collected from drainage ditches when water temperatures have dropped as low as 10 C. The storm sewers, which stay warmer than the surface environment, undoubtedly serve as warm water refuges during periods when winter water temperatures fall to lethal limits for *A. mexicanus*. Edwards (1977) documented a similar use of warm water by *A. mexicanus* in Austin, Texas. In Waller Creek, *A. mexicanus* is commonly caught in the summer when waters are warm. However, as water temperatures drop during the winter, *A. mexicanus* migrates to the deeper, warmer waters of the Colorado River. In Beaumont, *A. mexicanus* can be caught in the drainage ditches in the winter, but is more scarce than in the summer, indicating that they are migrating to Hildebrandt Bayou or the storm sewers during low water temperatures.

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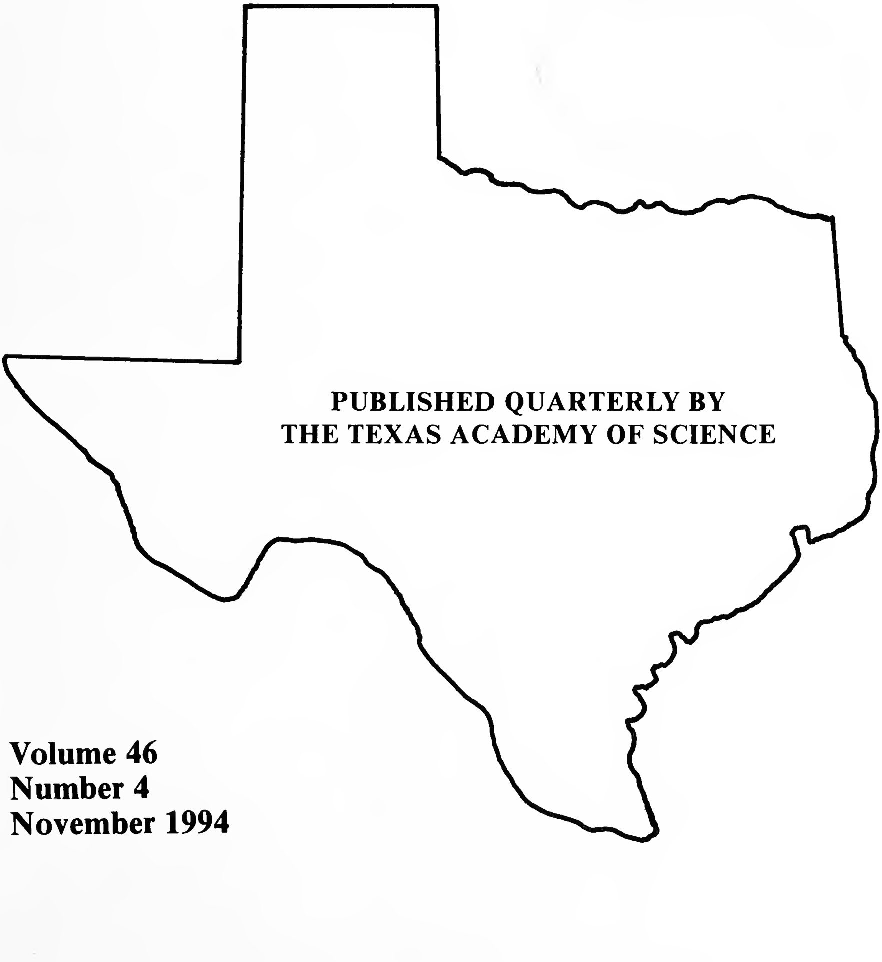

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OCCURRENCE PATTERNS AND BEHAVIOR OF BOTTLENOSE DOLPHINS (*TURSIOPS TRUNCATUS*) IN THE GALVESTON SHIP CHANNEL, TEXAS

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Abstract.—Surveys for bottlenose dolphins (*Tursiops truncatus*) were conducted in the Galveston Ship Channel between January 1990 and December 1992. Dolphins occurred year-round with seasonal peaks in spring and autumn. Many of the dolphins were well-marked and some appear to have scars resulting from human interactions. Dolphins observed in the Galveston Ship Channel appear to be part of an open population with no pronounced changes in the population size. Fifty-six individuals (23% of the individuals identified) were observed in all three years. Thirteen (23%) of the 56 dolphins were photographed as early as 1986/1987 in this same area, nine of these were determined to be females. Seventy-five percent of the 240 identified dolphins were sighted more than once during 1990-1992. Group sizes were small ($\bar{x}=3.2\pm$S.D.2.02 for groups without mother/calf pairs; $\bar{x}=2.9\pm$S.D.2.10 for groups with mother/calf pairs), and solitary dolphins were frequent (23% of groups with no mother/calf pairs were single individuals). The smallest groups, both with and without mother/calf pairs were observed in association with shrimp boats ($\bar{x}=2.7\pm$S.D.1.80 and $\bar{x}=2.7\pm$S.D.1.78, respectively), while the largest were socializing ($\bar{x}=3.7\pm$S.D.1.81 and $\bar{x}=4.2\pm$S.D.2.06, respectively).

The last 50 years has been characterized by a marked increase in studies conducted on the ecology of bottlenose dolphins (*Tursiops truncatus*) from coastal waters of the southeastern United States; particularly for dolphins in Florida and Texas. Gunter (1942, 1944, 1951, 1954) and Baughman (1946) provided the first opportunistic reports of Texas bottlenose dolphins. Bottlenose dolphin densities in Texas have since been reported by Shane and Schmidly (1978), Barham et al. (1980), Shane (1980), Gruber (1981), Leatherwood & Reeves (1983), Jones (1988), McHugh (1989), and Mullin et al. (1990). Detailed ecological studies have been conducted by Shane (1980), Gruber (1981), McHugh (1989), Henningsen (1991), and Bräger (1993). Most research had been limited to the Corpus Christi area; however, in the late 1980's through the early 1990's, studies were conducted in Galveston Bay (Jones 1988; Henningsen 1991; Bräger 1993, Bräger et al. 1994).

Bottlenose dolphins appear tolerant of human activities throughout their range (Leatherwood & Reeves 1982). Texas bottlenose dolphins occur in shallow and turbid waters which are often noisy, polluted, and near human population centers. The fact that bottlenose dolphins persist

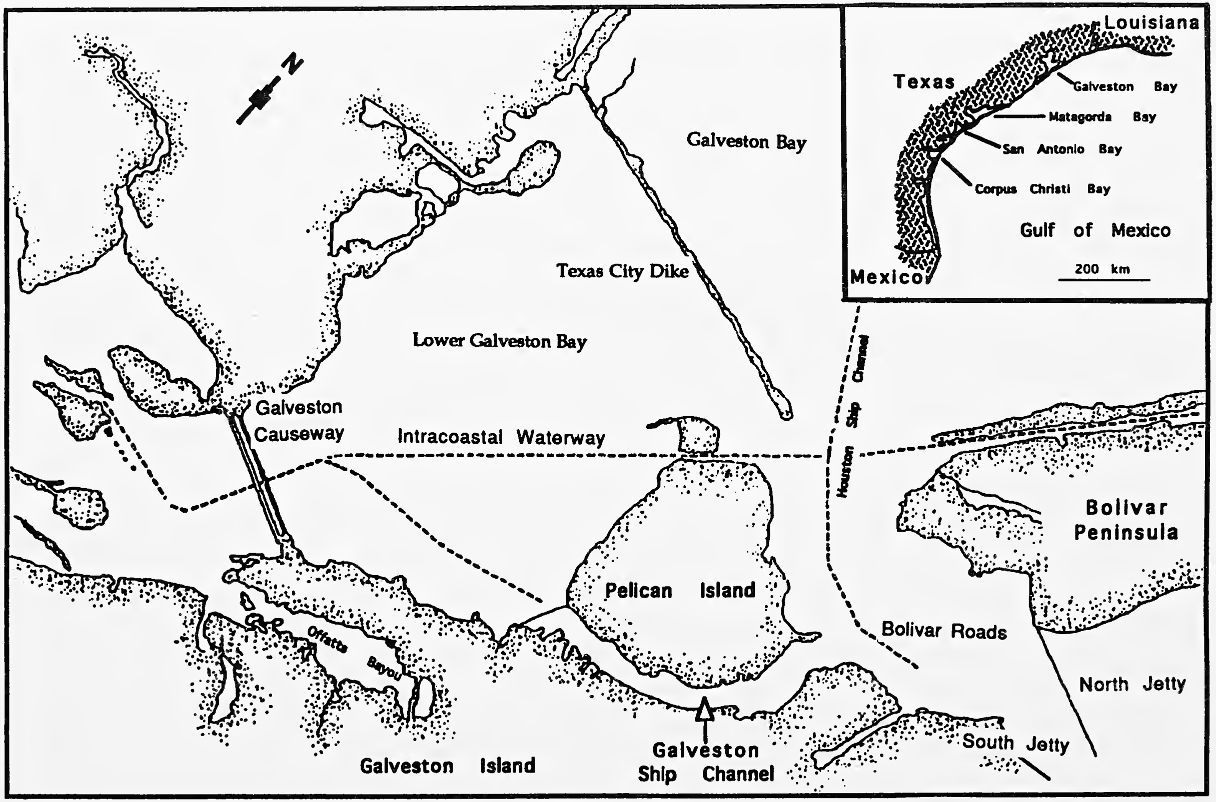

Figure 1. Map of Bolivar Roads and Lower Galveston Bay. Broken lines represent dredged areas for large vessel traffic. Inset map is of Texas coast.

in heavily trafficked ship channels and in areas of great human activity attests to their adaptability to human modified environments (Leatherwood & Reeves 1982).

The primary focus of this study was to investigate residence patterns and behaviors of dolphins which frequent the Galveston Ship Channel. It describes seasonal and inter-annual residence patterns, frequency of sightings, group sizes, and behaviors of identified dolphins.

Methods

Study Site.—The Galveston Bay complex is connected to the open waters of the Gulf of Mexico by two natural passes, Bolivar Roads and San Luis Pass. Bolivar Roads is an extensively modified area, with several dredged navigation channels, located in lower Galveston Bay between the northeast end of Galveston Island and southwestern tip of Bolivar Peninsula (Fig. 1).

The Galveston Ship Channel is one of the major channels in Bolivar Roads which facilitates commerce in the Galveston/Houston area. It is a 6.8 km long channel that is 342 m at the widest point, with a U-shaped bottom reaching a maximum depth of 12 m (T. Renny, U.S. Army Corp of Engineers, pers. comm.).

Survey Procedure.—The channel was surveyed by piloting a 5 m Boston Whaler at a slow speed in a meandering course always starting at the western end of the channel. Data were collected by two to four observers. Photographs of all individuals in each group encountered were taken and the group's behavior was recorded. Additional information noted included date, sighting conditions (weather and sea state), location, time of each group observation, group size and composition, and familiar animals.

Definition of Group.—A group of dolphins was one or more individuals engaged in the same activity within five dolphin body lengths of each other. Additionally, for shrimp boat associations, all dolphins following within 10 m behind or to the side of the stern of one shrimp boat were considered to be a group.

Recognition of Individual Dolphins.—The most commonly applied method for recognition of individual bottlenose dolphins is photo-identification by natural marks on the dorsal fin (Würsig &

Würsig 1977; Würsig & Jefferson 1990). Black and white photographs (Kodak T-MAX 400) and color slides (Kodachrome 200 and 64) were taken with 35 mm Nikon FM and Nikon 2000 cameras, equipped with 70-210 mm zoom lenses and motor drives. Photographs were printed from high quality negatives or slides. Dorsal fin photographs were catalogued by fin shapes and number and location of fin notches.

Definition of Age/Sex Classes.—The sex of dolphins was determined by one or more of the following criteria:
Female: observation of a calf consistently accompanying an adult; long genital slit and the presence of mammary slits [Though the presence of mammary slits should not be not used alone to determine sex of an animal since males sometimes develop skin folds that resemble mammary slits (Jefferson et al. 1994)];
Male: observation of an erect penis; a sexually dimorphic distance between the genital slit and anus.

A calf was considered to be an individual, two-thirds or less the length of an adult, that swam beside and slightly behind an adult (Shane 1990a). A mother was identified when it was an adult along with a calf, or observed as part of a group with a calf on several days. Repeated observations helped determine individuals as a mother (Shane 1990a). Juveniles were approximately two meters long and swam independently (Shane 1990a).

Behavioral Data.—Dolphin behavior was collected in an *ad libitum* manner (Altmann 1974), two to three minutes into the observation period, and then upon a change in group behavior. Observed behavior was classified into four major categories (traveling, milling, socializing, feeding) according to the definitions provided by Shane (1990a). In addition to these four categories, a sub-behavior of feeding was added: **Feeding in association with shrimp boats (FSB)**: repeated dives in varying directions around the side or behind the stern (the trawl cod end was approximately 20 m behind the stern) of a shrimp boat.

Seasonal Occurrence.—Seasons were defined as those by Shane (1977), Gruber (1981), Jones (1988): summer (June, July, August), fall (September, October, November), winter (December, January, February), and spring (March, April, May).

Seasonal patterns of occurrence was determined for the 56 individuals observed during all three years by pooling sightings by seasons.

Analysis by season was done to help correct for uneven survey effort within smaller time frames.

Inter-annual Sightings.—As examination of sighting patterns was conducted for identified dolphins to determine if any individuals exhibited inter-annual trends of residency. Each identified dolphin was placed in one of three categories of annual sighting (i.e. a dolphin was seen either during one, two, or all three years). A portion of the incomplete photo catalog of Michael Hunt of University of Houston-Clearlake, who previously photographed bottlenose dolphins in the study area, was reviewed to determine if any of the dolphins identified during the course of this study were observed as early as 1986/1987 in the area.

Data Set Partitioning.—For analysis of group size and behavior patterns, I used only data collected during April 1991 through March 1992, which not only reflected confidence in that data set, but also provided me with the most accurate description of group composition and behavior.

Mother/calf group data were analyzed in several ways to answer different questions. Calves were included as members of groups to determine if mother/calf pairs occurred in larger groups than other individuals. Calves were excluded from calculations for mean group sizes, to compare group sizes of non-calf individuals relative to behavioral state, and because a mother/calf pair were considered to be a behavioral unit.

Results

Survey Effort.—A total of 272 surveys, with approximately 880 hours spent in direct observation of dolphins, was conducted in the Galveston Ship Channel between January 1990 and December 1992. Dolphin groups were encountered on 90% (n=245) of these surveys.

Identified Dolphins.—Two hundred and forty individual dolphins were identified from natural dorsal fin markings. Twenty-seven were determined to be females and two were males. Several animals had wounds that were probably either the result of shark bites or boat propeller collisions and other human interactions.

Rate of Discovery.—The rate of discovery curve can provide information regarding immigration into a study area. The rate at which

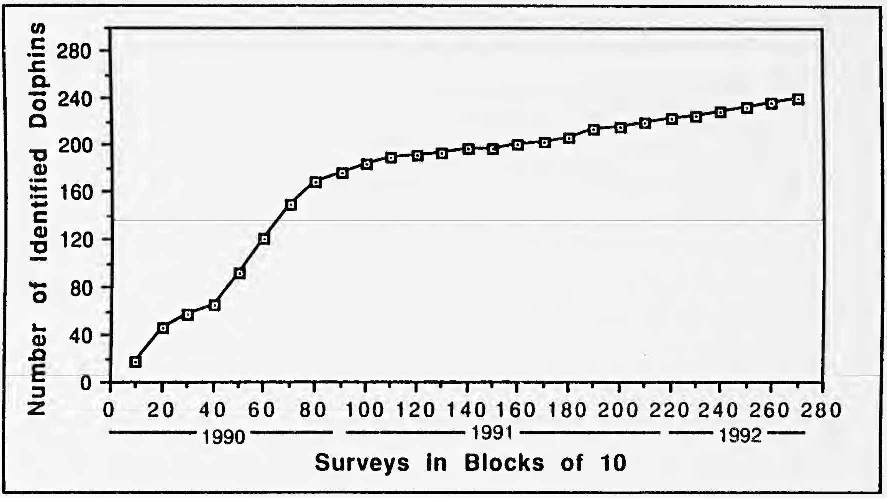

Figure 2. Cumulative rate at which individual dolphins were photo-identified in the Galveston Ship Channel. The data is presented in blocks of 10 surveys and the corresponding year is provided.

new dolphins were identified decreased at about ten months into the study (Fig. 2). Within ten months, or 80 surveys, 71% of the total number of dolphins using the study area had been photographed. The slight increase in the curve after 10 months demonstrates that new dolphins were continually being identified in the Galveston Ship Channel.

Inter-annual Sightings.—One hundred and two (42%) of the 240 identified dolphins were sighted only during one year, 82 (34%) during two years, and 56 (23%) in each of the three years. A minimum of thirteen dolphins (23%) of the 56 sighted in 1990-1992 were photographed as early as 1986/1987 in this area, and nine of these were females. Seven of these females were accompanied by a calf at some time during April 1991 - March 1992; one was classified as a juvenile, while the remaining animal was an adult female. The only other animals for which sex was determined, were accompanied by calves during April 1991 - March 1992.

Seasonal Occurrence.—The average number of identifiable individuals sighted per hour peaked in the late spring and early fall of each of the three years (Fig. 3).

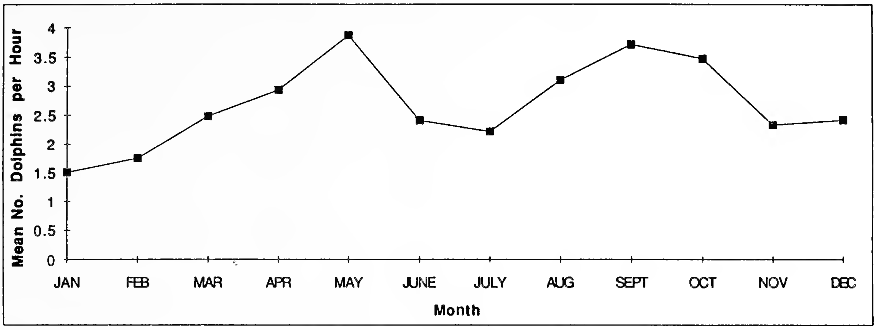

Figure 3. Mean number of recognizable dolphins sighted per hour per month in the Galveston Ship Channel during 1990-1992.

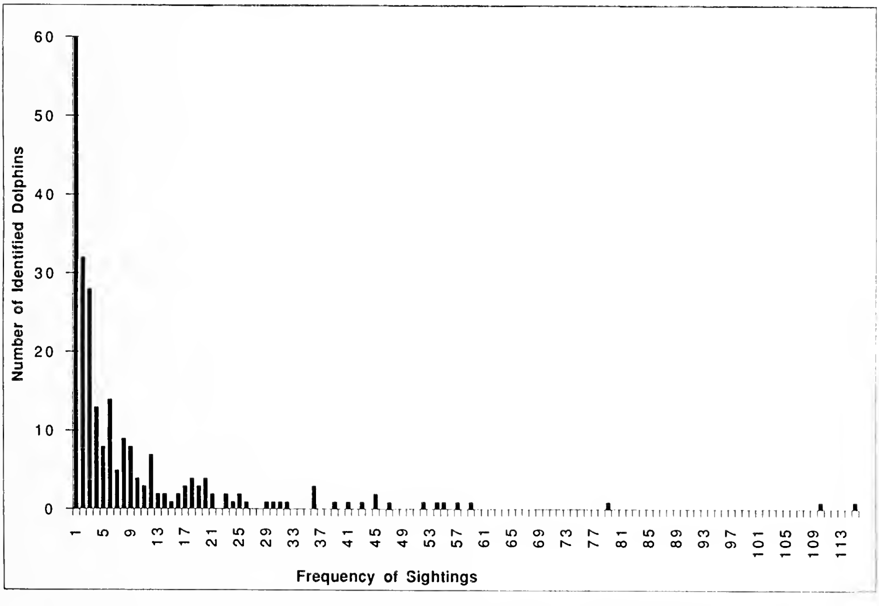

Figure 4. Frequency of sightings of identified dolphins for 1990-1992. For example, one dolphin was sighted on 115 separate days.

Forty-six percent (n=26) of the 56 dolphins sighted during all three years were sighted in multiple winters; 55% (n=31) in multiple springs; 46% (n=26) in multiple summers; 79% (n=44) in multiple falls.

Frequency of Resightings.—Number of sightings for the 240 identified dolphins ranged from one to 115 (Fig. 4). Seventy-five percent (n=180) of all dolphins were sighted more than once. The maximum number of sightings was for dolphin AAB, a juvenile female. Sixty-

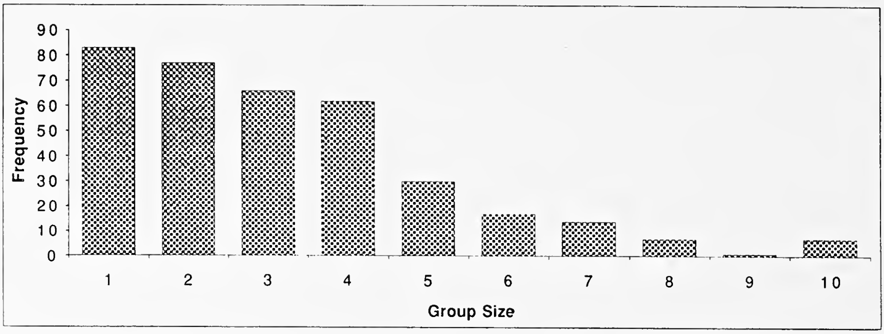

Figure 5. Frequency of group sizes for non-mother/calf groups in the Galveston Ship Channel.

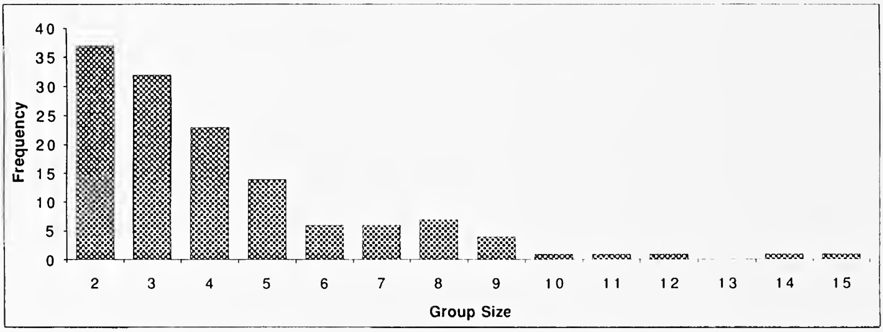

Figure 6. Frequency of group sized for mother/calf groups in the Galveston Ship Channel.

seven percent (n=160) of the dolphins were seen during April 1991 through March 1992; 47% (n=113) were sighted on more than one day. The highest number of sightings for any dolphin during this time period was 67 (again, dolphin AAB).

Group Size.—The 497 groups observed between April 1991 and March 1992 contained between one and 15 individuals. Twenty-seven percent of these groups (n=133) included at least one calf.

Groups without mother/calf pairs ranged in size from one to ten individuals (Fig. 5), with an overall mean of $\bar{x}=3.2\pm$S.D.2.02 (n=364). Twenty-three percent of these had only one individual present, while 79% had <5 individuals.

Groups with mother/calf pairs (including calves in the calculation) ranged in size from two to 15 individuals (Fig. 6). Seventy-three percent of these groups had only one mother/calf pair; 27% had two or more mother/calf pairs. Twenty-seven percent of these groups consisted only of the mother with her calf, while 73% had at least one individual accompanying a mother/calf pair. The overall mean size of groups with mother/calf pairs (excluding calves from the calculation) was $\bar{x}=2.9\pm$S.D.2.10 ($n=133$).

Group Size vs. Behavior.—The largest groups, both with and without mother/calf pairs, consisted of socializing dolphins ($\bar{x}=3.7\pm$S.D.1.81 and $\bar{x}=4.2\pm$S.D.2.06, respectively), while the smallest were those feeding behind shrimp boats ($\bar{x}=2.7\pm$S.D.1.80 and $\bar{x}=2.7\pm$S.D.1.78, respectively). Mean group size was significantly different among the five behavior categories for non-mother/calf groups, but not for groups that included mother/calf pairs (Kruskal-Wallis Rank Test: H=34.964, df=4, p=0.001; H=5.294, df=4, p=0.26, respectively).

Discussion

Survey Effort.—Dolphins were sighted during 90% of survey days. The findings indicate that dolphins utilize the Galveston Channel year-round, on almost all days.

Identified Dolphins - Causes of Natural Marks.—Many of the dolphins in this study had distinctive markings. Distinctive marks can be caused by natural pigmentation, scars from interactions with conspecifics, shark attacks, and marks due to human interactions. The latter two sources often cause particularly large marks (Würsig & Jefferson 1990).

Five individuals had visible crescent-shaped scars behind their dorsal fin. Wounds of this type were described by Wood et al. (1970) as shark bites. While the frequency of shark attacks on Galveston dolphins is unknown, the frequency of non-fatal attacks appears to be low. This is due to the fact that only 2% of the individuals identified during this study exhibited shark bites. Henningsen (1991) found that 5% of dolphins observed in the waters of Galveston Bay and the surrounding Gulf waters had scars on their backs that were most likely related to shark attacks. As noted by Ross (1977), it is possible that a lack of bite-scarred animals reflects a low escape rate. Shane et al. (1986) reported that dolphin remains were found most often in tiger, dusky (*Carcharhinus obscurus*), and bull sharks. Sharks from the family Carcharhinidae, such as tigers (*Galeocerdo cuvieri*) and bulls (*Carcharhinus leucas*), are common in the inshore waters of the Gulf of Mexico (Hoese & Moore 1977).

Collisions with boat propellers can cause injury or death of dolphins; this is probably more likely in areas where there are large concentrations of boats, such as the Galveston Ship Channel. Ten of the dolphins identified had obvious propeller cuts (clean v-shaped marks): four on their backs, five along the front edge of the dorsal fin, and one in its caudal peduncle. Others had grotesquely bent or cut dorsal fins, or had white scarring on the top that indicated the possibility of a serious cut. Collisions with boat propellers have been implicated in several cases of dolphin mortality in Texas waters (Shane 1977; Haubold et al. 1994; Reynolds 1985). Reynolds (1985) recommended that such situations be further studied to determine whether action should be taken to reduce dolphin mortality from propellers.

Two individuals exhibited marks from human interactions other than boat collisions: one had an apparent rope mark (a long indentation, with a roundish edge to it) that seemed to extend around the girth of the dolphin, while another one had a fluke that appeared to have been cut (probably by a knife due to its location and the straight-edge of the cut), or may have been a result of entanglement with fishing twine [as described for an adult spinner dolphin, *Stenella longirostris* by Green et al. (1991)].

Wound healing was observed in two animals during this study. Both animals - "Scarback" and "Gougeback", had deep propeller cuts. "Gougeback's" deep propeller cut may be classified a major wound [Lockyer and Morris (1990) classified body marks and scars into four different categories: superficial scratches; minor wounds and deeper scratches; deeper wounds; and major wounds], because it appeared to have penetrated the skin, blubber, and muscle, with a significant loss of tissue, and will probably leave a permanent indentation. "Gougeback's" wound healed by having the skin fold inwards, and within five months of the sighting, this wound became less visible. "Scarback" had propeller cuts similar to those seen on the back of manatees (Moore, 1956). These scars also healed in less than six months to the point that they were barely visible.

Very few individuals in the study area were observed to have the barnacle *Xenobalanus* on their dorsal fins or flukes. This lack of barnacles, which are common in dolphins south of this study area, greatly aided re-identification of individuals due to the fact that their fin notches were not covered. Only one individual was observed to exhibit a heavy barnacle encrustation on the dorsal fin and flukes.

Rate of Discovery.—Discovery of previously unidentified dolphins reached an asymptote after 10 months of survey effort. However, a continued but slight increase in the number of newly identified dolphins indicated that new individuals continued to visit this area. Other studies of bottlenose dolphins reveal discovery rates that also leveled off within the study period (Wells 1986; Ballance 1990; Shane 1987). Caution should be exercised in interpretation of the leveling trend (Shane 1987; Weller 1991) as long-term studies have revealed pulsed-recruitment of new individuals into the study area (Würsig 1978). Over the three years, however, I recorded no new pulse of previously unidentified individuals, suggesting that Galveston Ship Channel dolphins represent an open population with little net change in population size.

Other studies of Texas bottlenose dolphins also have shown an interplay of movement patterns: some individuals have restricted movements, while others move long distances at least at times (Shane 1980; Gruber 1981; Jones 1986, 1991). During this study, "new" individuals probably also immigrated from other parts of Galveston Bay, Texas inlets, or from the Gulf of Mexico. However, the low sighting rate of new dolphins over time indicates that the dolphins of Galveston Bay are quite different from the Pacific bottlenose dolphin population along southern California. Weller (1991) found that his discovery curve was relatively steep, and attributed this to extensive alongshore coastal movements by the dolphins in response to patchily distributed prey. It would be reasonable to assume that restricted areas, such as channels, that might concentrate food sources, would have a relatively higher resight rate than open habitat, which may require dolphins to make longer movements in response to prey distribution. Shane (1990b) observed that dolphins concentrated their activities in closed channels, and suggested that these areas provide more concentrated food sources. Additionally, Ballance (1992) found that estuary mouths attract feeding dolphins.

Inter-annual Sightings.—Twenty-three percent of the 240 photo-identified individuals were observed repeatedly during each of the three years of this study. Twenty-three percent of these repeatedly sighted individuals used the study area as early as 1986/1987. These 19 animals are probably only a minimum estimate of the number of dolphins exhibiting long-term site fidelity, because weather and operational constraints did not allow for equal effort on a year-round basis for prior studies.

Bottlenose dolphins in different areas display temporally variable occurrence (Wells 1986, Shane 1990a). Some animals are observed infrequently, while others are seen regularly. Dolphins sighted infrequently may be sighted again as a long-term study continues. Site fidelity is believed to be a common feature of coastal bottlenose dolphins (reviews by Leatherwood & Reeves, 1982; Shane et al. 1986). Würsig & Harris (1990) reported the resighting of members of a community in Argentina studied 8-12 years before, while some of the members of the Sarasota, Florida community have been known to inhabit that particular area for more than 21 years (Wells 1992). Recognizable individuals have frequented Shark Bay, Australia for over 20 years (Connor & Smolker 1985).

Seasonal Occurrence.—Observed increases were noted in the number of identified dolphins in spring and during late summer through fall. Similar findings for this area were reported by Hunt & Weeks (1990) & Jones (1988). Henningsen (1991) observed a similar increase in this area in autumn, but his study did not fully cover the spring months.

This study confirms the patterns observed in previous Texas studies (Shane 1980; Gruber 1981; McHugh 1989), that contrary to Gunter (1942), there is evidence for seasonal changes in dolphin abundance in Texas waters. Dolphin abundance in Port Aransas was twice as high in winter as in summer (Shane 1980; McHugh 1989), with similar trends for Matagorda Bay dolphins (Gruber, 1981). Jones (1988) attributed seasonal differences to the possibility of partial north-south migrations along the Texas shoreline. Researchers have attributed seasonal dolphin densities to associations with shrimp-fishing activities (Gruber 1981; Anonymous 1985); however, it is difficult to determine whether fish movements or shrimper operations were primarily responsible (Gruber 1981). Possible shifts in habitat use require further study of actual spatial and temporal distribution of prey. Seasonal movements by dolphins have been correlated with seasonal abundance of sharks in some areas such as Sarasota Bay, Florida (Wells et al., 1980) and Corpus Christi, Texas: (McHugh, 1989), but have not yet been studied for this area.

Frequency of Resightings.—A very high percentage (75%) of the 240 identified dolphins was resighted during the course of this study. Henningsen (1991) resighted only 14% of dolphins photo-identified in the Galveston area. His study area was mainly offshore in the Gulf and many of his animals may have been transient or ranging over a larger area. This current study was also conducted over a longer period of time than Henningsen's (1991).

The dolphins identified during this study may comprise a subset of a population or community that resides in Galveston Bay. The home range of the identified dolphins is not known. Dolphins sighted infrequently might represent another community or population, of which individuals occasionally move into Galveston Bay. Such an explanation has been suggested for the varying residence patterns of bottlenose dolphins in different locations (Shane et al. 1986; Wells et al. 1987) and short-finned pilot whales (*Globicephala macrorhynchus*) off Tenerife, Canary Islands (Heimlich-Boran 1993).

Group Size.—Commonly reported bottlenose dolphin group sizes are between two to 15 individuals; however, ranges between one and 100 individuals have been documented (review by Shane et al. 1986). Group size ranged from one to 15 dolphins in the Galveston Ship Channel. The small group sizes in this area are quite similar to observations made previously by Jones (1988) and Bräger et al. (1994). Twenty-three percent of the sightings of non-mother/calf pairs in my study were solitary dolphins, 27% of groups with mother/calf pairs were the mother and calf alone. While the sighting percentage of lone dolphins in the Galveston Channel is not high, it is greater than that previously reported for this species (10% for Matagorda Bay, TX by Gruber 1981; less than 15% near Sarasota, FL by Irvine et al. 1981; 12-18% for Sanibel Island, FL by Shane 1990a).

Habitat structure, in terms of complexity and water depth, is generally a major force that shapes bottlenose dolphin groupings (Leatherwood & Reeves 1982; Shane et al. 1986). Groups tend to be smaller in marshlands and estuaries, where acoustic contact and coordinated activities would be difficult. Open or deep-water areas typically have larger group sizes than shallow waters (Shane et al. 1986) or constricted areas such as channels or passes (Gruber 1981). The small group sizes observed during this study are comparable to those reported in closed coastal studies from various areas of Texas, such as Aransas Pass (Shane 1977), and Matagorda Bay (Gruber 1981), as well as for Sarasota, Florida (Wells et al. 1980). Off the coast of Texas and Florida, the continental shelf is wide and extends far, and the deeper waters of the Gulf of Mexico are further offshore. Larger group sizes have been described for bottlenose dolphins in exposed coastal areas (where the continental shelf is narrow, and deep waters are close to shore) such as

Argentina (Würsig 1978); California (Weller 1991); Kino Bay, Gulf of California (Ballance 1990); and Mississippi Sound (Leatherwood & Platter 1975). Henningsen (1991) did not find a difference between group sizes in Galveston Bay and surrounding Gulf waters. Gruber (1981) observed that open water groups tend to be larger than those in constricted areas such as channels or passes.

The evolutionary advantages of group living include increased vigilance and protection against predators; passive or active transfer of information on the presence of patchily distributed resources; increased ability to capture or subdue prey, and increased ability to gain access to and defend resources (Bertram 1978; Clark and Mangel 1986). Predation pressure and patterns of food distribution are considered to be two of the most important ecological factors shaping average group size (Pulliam & Caraco, 1984). Group size related to physiography has been linked to availability of resources and predation pressure (Norris & Dohl 1980; Wells et al. 1980; Weller 1991). Inshore waters often provide predictable and confined food resources, particularly in the case of this study area where bait shrimping occurs year-round and fish tend to school around docks and non-working oil rig platforms. Therefore, it would appear that the restricted habitat and predictable food sources have resulted in smaller group sizes in this study area than in some of the other more open ocean or deeper water studies.

Group Size vs. Behavior.—Bottlenose dolphin group size is often a reflection of activity patterns (Shane et al. 1986). The mean group sizes for all groups in this study were largest during socializing and smallest for feeding with shrimp boats. Groups foraging away from shrimp boats were slightly larger than those feeding near shrimp boats. Dolphins integrating their sensory capabilities increase the probability of locating patchily distributed food sources, in the form schooling fish (Norris & Dohl 1980; Würsig 1986). Because shrimp boats represent a predictable food source, and are probably easy for dolphins to find by listening for the motors, this may explain the smaller group size.

Findings from this study support similar observations of dolphin group sizes relative to behavioral states in Galveston (Bräger 1992), Port Aransas (Shane 1977), and Sanibel Island (Shane 1990a). Average group size of dolphins with shrimp boats was within the range found by Gruber (1981) for dolphins associated with bay shrimpers.

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BODY MASS, DEVELOPMENTAL STAGE, AND INTERSPECIFIC DIFFERENCES IN ACID TOLERANCE OF LARVAL ANURANS

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Abstract.—The relationships of body mass and developmental stage to acid tolerance were examined in tadpoles of three species of anurans from central Texas: *Bufo woodhousei*, *Bufo valliceps*, and *Gastrophryne olivacea*. Significant differences in survival time at low pH occurred among all three species (survival time of *Bufo valliceps* > *Bufo woodhousei* > *Gastrophryne olivacea*). Body mass and developmental stage were significantly correlated, and their relationship to survival time was complex and species specific. Multiple regression analysis indicated that for *Bufo woodhousei*, mass was positively associated with survival time; there was no effect of developmental stage independent of its correlation with mass. For *Bufo valliceps*, mass was positively associated with survival time, whereas developmental stage was negatively associated with survival time. Neither mass nor developmental stage were significantly associated with survival time in *Gastrophryne olivacea*.

Reports of widespread amphibian declines (Barinaga 1990; Wake 1991) and concerns about the deleterious influence of acid precipitation on amphibian communities have stimulated an increase in recent research on the effects of acidity on amphibians (Freda 1986; Pierce 1993). Although there is little current evidence that acid deposition is responsible for amphibian declines (Dunson et al. 1992; Pierce 1993), this research has provided important information as to how amphibians respond to variation in pH. In general, amphibian larvae are more tolerant of acidity than embryos, and acid tolerance of amphibian larvae increases as larvae grow and develop (Pierce et al. 1984; Freda & Dunson 1985; Freda & MacDonald 1989).

In addition to this ontogenetic variation, there are interspecific (Freda & Dunson 1985; Warner et al. 1991), interpopulation (Pierce & Harvey 1987), and intrapopulation (Pierce & Sikand 1985; Pierce & Wooten 1992) differences in acid tolerance of tadpoles. However, the extent to which these differences in acid tolerance are related to differences in body mass remains unclear. For example, body mass and developmental stage are usually correlated within species, and the increased acid tolerance reported for more developmentally advanced larvae might be simply a consequence of increased body mass. Also, if body mass is important in determining acid tolerance among larvae, the effect of mass should be removed before assessing inter- and intraspecific differences. This investigation examines these issues by studying the associations of body mass and developmental stage to acid tolerance in larvae of three species of anurans: *Bufo woodhousei*, *Bufo valliceps*, and *Gastrophryne olivacea*.

Materials and Methods

Tadpoles of *Bufo woodhousei*, *Bufo valliceps*, and *Gastrophryne olivacea* were collected from a small ephemeral pond located in McLennan County, Texas on 20 May 1991. Adults of all three species had reproduced two weeks earlier during rainfall that filled the pond; thus all larval specimens were approximately the same age. Following collection, the tadpoles were transported to the laboratory, separated by species, and placed in neutral (pH 7.2-7.7) reconstituted soft water (RSW), which consisted of 48 mg $NaHCO_3$, 30 mg $MgSO_4$, 30 mg $CaSO_4 \cdot 2H_2O$, and 2 mg KC1 dissolved in one liter of deionized H_2O (Stephen 1975). Specimens were kept in an incubator at 25 C on a 12 hr light: 12 hr dark photoperiod for 24 hours prior to testing and were not fed during this period.

Immediately prior to testing acid toxicity, each specimen was weighed with the following procedure. A small capped vial containing neutral RSW was weighed on an analytical balance to the nearest 0.0001 g. The specimen was carefully removed from its container with a small mesh net, briefly placed on a wet sponge to remove excess water adhering to the body, and transferred to the weighed vial with a stainless steel spatula. The vial was then capped and reweighed to the nearest 0.0001 g. Wet body mass of the tadpole was then obtained by subtraction. After weighing, each specimen was placed in an individually marked glass beaker containing neutral RSW. The weighing procedure causes no injury or obvious stress to tadpoles (Cummins 1986).

After all specimens were weighed, they were transferred to the test solutions, which consisted of unaltered, neutral RSW (pH 7.2-7.7) or RSW acidified to pH 3.5 with dilute sulfuric acid. A pH 3.5 test solution was used because preliminary tests indicated that this pH produced mortality in all three species during the 72-hour test period. Each specimen was tested individually in 300 ml of solution contained within a 400 ml glass beaker covered with a watch glass. Prior to testing, all beakers and watch glasses were washed with soap and water, rinsed once with tap water, rinsed twice with deionized water, rinsed once with 0.1 M HNO_3, and rinsed twice more with deionized water.

Fifteen specimens of each species were tested in the neutral solution, and 30 specimens of each species were tested in the acidic solution, for a total of 135 test subjects. Specimens were randomly assigned to the treatment groups.

Mortality was assessed by lightly touching each specimen with a small, flat, stainless steel spatula; specimens that failed to respond to this stimulus by exhibiting movement were considered dead. All surviving tadpoles were checked for mortality at 1, 2, 4, 8, 12, 24, 36, 48, 60, and 72 hours after the start of the experiment. Throughout the test period, each beaker was maintained at 25 C on a 12 hr light: 12 hr dark photoperiod. (The dark phase was interrupted briefly during mortality checks.) The positions of beakers within the incubator were randomized at the beginning of the experiment, and they were rerandomized every 24 hours. To minimize pH drift, test solutions were replaced with fresh solution every 24 hours. Before changing solutions, pH was measured in five randomly selected beakers of acidic solution and five randomly selected beakers of neutral solution. Specimens were not fed during the test period.

All specimens that expired during the experiment were immediately preserved in 10% formalin. At the end of the experiment, five surviving specimens of each species from the neutral solution were randomly selected, anesthetized in MS-222, and then preserved in 10% formalin. All other surviving specimens were returned to their native pond. Developmental stage (Gosner 1960) was determined on preserved specimens by examination using a dissecting microscope. For statistical testing, survival time was log transformed ($\log_{10}$ of [time + 1]). Analysis of variance and regression were used to examine the relationship of mass, developmental stage, and species to survival time. The experiment-wise error rate was considered to be 0.05.

Results

The pH of the test solutions drifted slightly during the 24 hours between solution changes. For the pH 3.5 solution, the average pH at the end of 24 hours between solution changes was 3.61 (range = 3.54-3.68); for the pH 7.2-7.6 solution, the average pH at the end of 24 hours was 7.56 (range = 7.36-7.7).

The tadpoles of the three species tested differed in developmental stage (F = 53.83; d.f. = 2, 96; $P < 0.001$). *Bufo valliceps* tadpoles were the most advanced, with an average Gosner stage of 29 (Table 1).

Table 1. Mean (± standard error) of mass, developmental stage (Gosner 1960), and survival time at pH 3.5 of *Bufo woodhousei*, *Bufo valliceps*, and *Gastrophryne olivacea* tadpoles.

Species	Mass (g)	Stage	Survival Time (hr)
Bufo woodhousei	0.025 ± 0.001	26.4 ± 0.14	4.8 ± 0.46
Bufo valliceps	0.047 ± 0.002	28.9 ± 0.20	22.5 ± 3.1
Gastrophryne olivacea	0.047 ± 0.002	27.0 ± 0.19	2.9 ± 0.20

The Scheffe-F test for *a posteriori* comparisons indicated that the larvae of *Bufo valliceps* were more advanced than those of *Bufo woodhousei* and *Gastrophryne olivacea*, but the latter two species did not differ significantly from one another. Significant differences also occurred in average tadpole mass of the three species at the beginning of the experiment (F = 62.17; d.f. = 2,132; $P < 0.001$). *Bufo valliceps* and *Gastrophryne olivacea* did not differ significantly in wet mass (both averaged 0.047 g), but both were significantly heavier than *Bufo woodhousei* tadpoles (average mass = 0.025 g, Table 1). Developmental stage and wet mass were positively correlated within each species (for *Bufo woodhousei* r = 0.60, d.f. = 31, $P < 0.001$; for *Bufo valliceps* r = 0.78, d.f. = 33, $P < 0.001$); for *Gastrophryne olivacea* r = 0.70, d.f. = 32, $P < 0.001$). The slopes of the regressions of mass and stage were similar in all three species.

No specimen in the neutral pH treatment group expired during the 72-hour test; therefore, our analysis is restricted to survival in the acidic solution (pH 3.5). In the acidic solution, all tadpoles died within 60 hours, and there were significant differences in survival time among species (F = 80.06; d.f. = 2, 87; P = 0.0001). *A posteriori* comparisons (Scheffe-F test) indicated that each species differed significantly from the other two species in survival time. *Bufo valliceps* tadpoles lived much longer on the average than did tadpoles of the other two species (Table 1). Large numbers of *Gastrophryne olivacea* and *Bufo woodhousei* larvae died early in the experiment (100% mortality at 4 and 12 hours, respectively), whereas mortality of *Bufo valliceps* larvae began later and occurred over a broader range of time (4 hours to 60 hours). Although both *Gastrophryne olivacea* and *Bufo woodhousei* tadpoles died relatively early compared to *Bufo valliceps, Bufo woodhousei* tadpoles survived significantly longer than those of *Gastrophryne olivacea*.

Table 2. Multiple regression of mass and stage on survival time in three species of tadpoles. d.f. = degrees of freedom for correlation, r = correlation coefficient, ßmass = standardized beta coefficient for mass, tmass = t value for mass, ßstage = standardized beta coefficient for stage, and tstage = t value for stage in multiple regression. * Designates $P<0.05$; ** designates $P<0.01$.

Species	F	d.f.	r	ßmass	tmass	ßstage	tstage
Bufo woodhousei	9.7	26	0.67**	0.70	3.45**	-0.05	0.27
Bufo valliceps	4.25	28	0.50*	0.81	2.89**	-0.71	2.52*
Gastrophryne olivacea	1.81	27	0.36	0.14	0.54	0.25	0.97

Mass and survival time at low pH were significantly correlated in *Bufo woodhousei* tadpoles (r = 0.65, d.f. = 29, P = 0.03), but there was no significant relationship between mass and survival time in *Bufo valliceps* (r = 0.24, d.f. = 29, P = 0.21) nor in *Gastrophryne olivacea* (r = 0.27, d.f. = 29, P = 0.27). Similarly, developmental stage and survival time were significantly correlated in *Bufo woodhousei* (r = 0.42, d.f. = 26, P = 0.03), but not in *Gastrophryne olivacea* (r = 0.34, d.f. = 27, P = 0.08) nor in *Bufo valliceps* (r = -0.061, d.f. = 28, P = 0.75).

Because mass and developmental stage are correlated and both are correlated with survival time in *Bufo woodhousei*, we used multiple regression to examine the independent effects of mass and stage on survival time (Table 2). For *Bufo woodhousei*, the overall regression was significant. Mass was positively associated with survival time (standardized beta = 0.704), but there was no significant association of stage independent of its correlation with mass. For *Bufo valliceps*, the overall regression was significant, and both stage and mass had independent effects on survival time. Mass was positively correlated with survival time (standardized beta = 0.81), whereas developmental stage exhibited a negative correlation (standardized beta = -0.71) once the effect of mass on survival time was removed. The overall regression in *Gastrophryne olivacea* was not significant.

Discussion

Previous studies found that acid tolerance of amphibian larvae increases with development (Pierce et al. 1984; Freda & Dunson 1985;

Freda & MacDonald 1989) and that interspecific and intraspecific differences occur in tadpole acid tolerance (Freda & Dunson 1985; Pierce & Sikand 1985; Pierce & Harvey 1987). However, the extent to which differences in body mass were responsible for these developmental and individual differences was not examined. In tadpoles, surface-to-volume ratio, buffering capacity, and general hardiness (all of which likely affect the sensitivity of amphibian larvae to low pH conditions) are correlated with body mass. Thus, there is reason to suspect that increases in body mass associated with growth and development in tadpoles are likely to result in increased acid tolerance, but the precise relationship between body mass, developmental stage, and acid tolerance has not been studied previously in these animals.

The tadpoles used in this experiment were collected from a pond with relatively high pH (pH 7-8), so the test subjects would not have been previously exposed to acidic conditions. However, the ranges of all three species extend into areas with poorly buffered soils and acidic habitats (in east Texas). Some ponds and streams in east Texas have pHs regularly below 4 and as low as 3.1; we have collected tadpoles from one pond where the pH was frequently below 4.0 (unpublished observations). Thus, tadpoles may be exposed to low pHs under natural conditions.

In interpreting the results of our experiments, it is important to keep in mind that this study examined acid tolerance over a relatively restricted range of body mass and development stage. Larval specimens were purposely chosen that were approximately the same age, so that it could be determined whether species differences are explained by differences in growth and developmental rates. Different results might have been obtained had one used larvae with larger differences in body mass, or larvae that were at the extremes of the developmental sequence.

Results obtained during this study point to several important conclusions. First, it is clear that different amphibian species exhibit different relationships among body mass, developmental stage, and survival time in low pH conditions. Body mass and stage were associated with survival time in *Bufo* tadpoles (though their interactions were complex), but there was no evidence for an effect of either mass or stage on acid tolerance in *Gastrophryne olivacea*. Second, body mass displayed a positive relationship to survival time; this was evident from both the univariate analysis and the multiple regression, although the correlation was not significant in all three species. The significant effect of body mass in the multiple regression (for *Bufo woodhousei* and *Bufo* *valliceps*) indicates that mass has an association with survival time that is independent of developmental stage. This association makes sense because increasing body mass increases buffering capacity and reduces the surface-to-volume ratio of the animal, both of which reduce sensitivity to acidity. These findings suggest that the effects of body mass should be assessed and statistically removed in future studies that examine ontogenetic, interspecific, or intraspecific differences in acid tolerance of larvae.

The relationship between developmental stage and survival time was more complex. In the univariate analysis, stage exhibited a positive correlation with survival time, although the correlation was only significant for *Bufo woodhousei*. However, this correlation appears to be largely the result of the positive correlation between mass and developmental stage. When multiple regression was applied and the effect of body mass removed, developmental stage actually had a negative relationship to survival time (significant only in *Bufo valliceps*). This finding indicates that among tadpoles of similar mass, those that are more developmentally advanced may actually be less tolerant. Thus, the increase in acid tolerance previously observed with development (Pierce et al. 1984; Freda & Dunson 1985; Freda & MacDonald 1989) may be largely the result of increases in body mass. However, it is important to note that this study examined acid tolerance over a narrow range of tadpole development, and developmental variation may play a more important role in acid tolerance among tadpoles from a wider range of stages.

An important question is whether species differences in acid tolerance are independent of variation in body mass and developmental stage. Normally, this question might be addressed with covariance, using body mass and stage as covariates in an analysis of mean differences in survival time among the species. However, analysis of covariance requires that the slopes of each covariate (body mass of developmental stage) with the dependent variable (survival time) be similar among groups. This is clearly not the case in this study, as the relationships were significant in some species and not significant in others; thus the assumptions of covariate analysis cannot be met. Nevertheless, simple inspection of the data suggests that body mass and developmental stage do not account for all the differences which were observed in survival time among the three species. For example, *Bufo valliceps* and *Gastrophryne olivacea* had the same mean body mass, yet *Bufo valliceps* exhibited much longer survival time than *Gastrophryne olivacea*. Also, *Bufo woodhousei* and *Gastrophryne olivacea* did not differ in developmental stage, but their survival times were significantly different. These observations indicate that there are fundamental differences in acid tolerance between species that are not a simple function of differences in body mass and developmental stage.

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CELL WALL DEGRADING ENZYMES PRODUCED BY THE PHYTOPATHOGENIC FUNGUS *COLLETOTRICHUM GLOEOSPORIOIDES*

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Abstract.—The extracellular cell wall degrading enzymes of *Colletotrichum gloeosporioides* and the effect of different carbon sources on the production of these enzymes were investigated. Cellobiohydrolase and xylanase activities were detected in fluids collected from cultures containing microcrystalline cellulose, sodium carboxymethyl cellulose (CMC), or xylan. Maximum production of cellobiohydrolase and xylanase was induced when CMC was the sole source of carbon. The highest activity of endoglucanase was measured in fluids collected from cultures containing xylan. Results of this study indicate that *C. gloeosporioides* constitutively produces endoglucanase and xylanase.

Direct penetration of susceptible hosts by the infective hyphae of phytopathogenic fungi is facilitated by the production of cutinases (Agrios 1988), followed by softening or disintegration of host tissues by cell wall degrading enzymes produced by the pathogen (Kenaga 1974; Agrios 1988). Production of these enzymes may be induced in many plant pathogenic fungi when the organisms are grown on media containing various sugar polymers (Cooper & Wood 1973; Pegg 1981; Ortega 1990).

Colletotrichum gloeosporioides (Penz.) Sacc., anamorph of *Glomerella cingulata* (Ston.) Spauld. & Schrenk., exhibits a wide range of host species which includes many plants of economic importance. This species is known to cause leaf spots on ornamental plants such as calendula, hibiscus, jasmine and passiflora (Pirone 1978). It also attacks tropical plants causing cacao anthracnose, coffee dieback and yam anthracnose (Cook 1978) and causes anthracnose diseases and fruit rot in strawberries and apples (Maas & Howard 1985).

The primary objectives of this study were to determine the components of extracellular cell wall degrading enzymes of *C. gloeosporioides* and to determine the effects of the carbon source on the production of these enzymes by *C. gloeosporioides*.

Materials and Methods

Organism and culture conditions

Stock cultures of *C. gloeosporioides* were maintained on PDA slants

(Difco, B13). The fungus was previously grown in 250 ml flasks with 125 ml of a medium containing: 0.02 percent $MGSO_4.7H_2O$, 0.01 percent $Ca(NO_3)_2.4H_2O$, 0.1 percent peptone, 0.2 percent yeast extract, 2.0 percent glucose in sodium citrate buffer at pH 5.0. After four days growth at 26°C, five ml of mycelium inoculum were washed twice in distilled water and then transferred to the cellulolytic growth medium. The medium for the production of cellulases contained: 0.25 percent NH_4NO_3, 0.10 percent K_2PO_4, 0.05 percent $MgSO_4$, 0.05 percent $Ca(NO_3)_2.4H_2O$, 0.72 ppm $Fe(NO_3)_3.9H_2O$, 0.44 ppm $ZnSO_4.7H_2O$, 2.0 ppm $MnSO_4.4H_2O$, 0.40 ppm $ZnCl_2$, 0.8 percent carbohydrate. The carbohydrates used as carbon sources and enzyme inducers were: sodium carboxymethyl cellulose (CMC, Aqualon Company, type 7HF), microcrystalline cellulose and xylan (Sigma Chemical Company). Control cultures contained glucose as the sole carbon source. The pH of the growing medium was adjusted to 5.0 with 0.1N KOH. Incubation of the cultures was carried out for seven days in covered 250 ml flasks on an orbital shaker at 80 rpm and 26°C.

Enzyme preparation and assays

Culture fluids were collected after seven days of growth by centrifugation (4500 rpm, 30 minutes, 10°C). The supernatant was subsequently used for the determination of extracellular enzyme activity. For simplification, the collected supernatant is hereafter referred to as the enzyme. All tests were replicated four times.

Cellobiohydrolase (1,4-B-D-glucan cellobiohydrolase, EC 3.2.1.91). Cellobiohydrolase activity was measured by combining in separate test tubes one ml of enzyme with 10 milligrams of microcrystalline cellulose in one ml of 0.05 M sodium citrate buffer (pH 5.0) and incubating the reaction mixture for two hours at 40°C . The tubes were stirred several times during incubation. After centrifugation, the concentration of reducing sugar in the supernatant was determined by the dinitrosalicylic acid method of Miller (1959).

Endoglucanase (CM-cellulase, carboxymethyl cellulase, EC 3.2.1.4). Endoglucanase activity was measured by combining one ml of enzyme with 20 mg of carboxymethyl cellulose in 0.05 M sodium citrate buffer, pH 5.0. The reaction mixture was incubated at 40°C for 30 minutes. The concentration of reducing sugar in the reaction mixture was determined by the dinitrosalicylic acid method of Miller (1959).

Xylanase (EC 3.2.1.32). Xylanase activity was measured by combining 10 mg of xylan in one ml of 0.05 M sodium citrate buffer pH 5.0, with one ml of enzyme. The reaction mixture was incubated at 40°C for 30 minutes. After centrifugation, the concentration of reducing sugars in the supernatant fluid were determined by the dinitrosalicylic acid method of Miller (1959).

Protein determination

Extracellular protein in the crude supernatants was determined with the BCA reagent (Pierce Chemical Company) using bovine serum albumin as a standard.

Data analysis

The results were expressed as units of specific enzyme activity and represent means plus or minus the standard deviation of four replications. One unit of specific activity (U) was calculated as the amount of enzyme that liberated 1.0 micromole (μM) of glucase, xylose or their reducing sugar equivalents per minute per ml of enzyme per mg of extracellular protein at pH 5.0 at 40°C. Statistical analyses of experimental data were made using the Student's t-test.

Results

Cellobiohydrolase

Production of cellobiohydrolase was induced in cultures with microcrystalline cellulose, CMC and xylan. No cellobiohydrolase activity was detected in the cultures with glucose as the sole carbon source. Maximum cellobiohydrolase activity (22.86 U) was measured in fluids from cultures containing CMC (Table 1). This activity was significantly higher ($p \leq 0.001$) than cellobiohydrolase activities measured in fluids from cultures with microcrystalline cellulose or xylan. Cellobiohydrolase activities measured in fluids from cultures containing microcrystalline cellulose or xylan were 15.0 percent and 9.4 percent, respectively, of the activity measured in fluids from cultures with CMC. The difference between the cellobiohydrolase activity measured in fluids from cultures containing microcrystalline cellulose and the activity determined in fluids from cultures with xylan was not statistically significant.

Table 1. Specific activities[1] of cell wall degrading enzymes produced by *Colletotrichum gloeosporiodes* grown with different carbon sources.

	Enzymes			
Carbon source	Cellobiohydrolase	Endoglucanse	Xylanase	Extracellular protein[2]
Microcrystalline cellulose	3.44±0.10	14.11±0.18	15.09±0.19	0.09±0.02
CMC	22.86±0.20	0.0[3]	147.69±4.25*	0.15±0.01
Xylan	2.15±0.13	52.28±1.41*	69.11±0.83	1.74±0.08
Glucose	0.0[3]	33.40±2.26	33.32±0.60	4.74±0.04

[1] μM of glucose, xylose or their reducing sugar equivalent/min/ml/mg of protein. Mean ± SD of four replications.

[2] mg/ml.

[3] 0.0 no enzyme activity detected.

* Using Student's t-test, significantly ($p \leq 0.001$) different from control (glucose).

Endoglucanase

Maximum endoglucanase activity (52.28 U) was measured in culture fluids of *C. gloeosporioides* when the fungus was grown in media containing xylan (Table 1). This activity was significantly higher ($p \leq 0.001$) than the endoglucanase activities measured in fluids with microcrystalline cellulose or glucose. The activities of this enzyme measured in fluids from cultures with microcrystalline cellulose or glucose were 26.9 percent and 63.8 percent, respectively, of the activity measured in fluids from cultures containing xylan (Table 1). Endoglucanase activities measured in the fluids from cultures containing glucose (33.40 U) were significantly higher ($p \leq 0.001$) than the activities measured in fluids from cultures containing microcrystalline cellulose (14.11 U, Table 1). The lowest endoglucanase activity (14.11 U) was measured in cultures that had microcrystalline cellulose as the enzyme inducer (Table 1). No endoglucanase activity was detected in fluids collected from cultures containing CMC as the carbon source.

Xylanase

Production of xylanase by *C. gloeosporioides* was induced in all cultures (Table 1). Maximum production of this enzyme (147.69 U) was measured in the cultures that contained CMC as the carbon source. This activity was significantly higher ($p \leq 0.001$) than the activities measured in fluids from cultures containing microcrystalline cellulose, xylan or glucose. Xylanase activities measured in fluids from cultures with microcrystalline cellulose, xylan or glucose were 10.2 percent, 46.8 percent and 22.5 percent, respectively, of the activity measured in fluids from cultures containing CMC (Table 1). The activities of xylanase measured in fluids from cultures containing xylan were significantly higher ($p \leq 0.001$) than the activities measured in fluids from cultures containing microcrystalline cellulose or glucose (15.09 U and 33.32 U, respectively). Xylanase activity assayed in fluids containing glucose was significantly higher ($p \leq 0.001$) than the activity (15.09 U) measured in fluids with microcrystalline cellulose as enzyme inducer. The activity of this enzyme induced by microcrystalline cellulose was the lowest xylanase activity measured in this study.

Discussion

Maximum production of cellobiohydrolase by the test fungus was measured in fluids from cultures containing CMC. Similar results were obtained in other studies of the phytopathogenic fungi *Fusarium oxysporum* f. sp. *lycopersici* (cf. Ortega 1990) and *Exserohilum rostratum* (cf. Ortega 1993). However, in studies of *Alternaria brassicae* (cf. Ortega 1992), it was found that the highest production of cellobiohydrolase was induced by microcrystalline cellulose. Apparently, *C. gloeosporioides* did not produce cellobiohydrolase constitutively under the conditions of this study. The phytopathogenic fungi *A. brassicae* and *E. rostratum* constitutively produce small amounts of this enzyme (Ortega 1992; 1993).

The highest activity of endoglucanase was measured in fluids from cultures of *C. gloeosporioides* containing xylan. Whereas CMC did not induce the production of this enzyme by the test fungus, maximum activities of endoglucanase were induced by CMC in cultures of the plant pathogenic fungi *F. oxysporum* f. sp. *lycopersici* (cf. Ortega 1990) and *E. rostratum* (cf. Ortega 1993). Endoglucanase activity measured in the fluids of the control cultures was ca. 64 percent of the activity evaluated in the fluids from cultures of the fungus with maximum enzyme activity. Endoglucanase activity produced in the absence of the enzyme inducer (CMC) suggests that the *C. gloeosporioides* constitutively produces endoglucanase. It was previously shown that endoglucanase was produced in a constitutive manner by the plant pathogenic fungi *F. oxysporum* f. sp. *lycopersici* (cf. Ortega 1990), *A. brassicae* (cf. Ortega 1992) and *E. rostratum* (cf. Ortega 1993).

Maximum production of xylanase was measured in fluids from cultures with CMC as carbon source and enzyme inducer. Ortega (1993) demonstrated that this carbon source also induced maximum xylanase activities in fluids of liquid cultures of *E. rostratum*. In similar studies of *F. oxysporum* f. sp *lycopersici* (cf. Ortega 1990) and *A. brassicae* (cf. Ortega 1992) the highest xylanase activities were measured in fluids of cultures containing xylan as the carbon source. Xylanase activity determined in the fluids of the control cultures was nearly 23 percent of the highest xylanase activity measured in this study. The activity of this enzyme produced in the absence of the enzyme inducer (xylan) suggests that a certain amount of the xylanase produced by *C. gloeosporioides* was synthesized in a constitutive manner. It has been previously demonstrated that this enzyme is also produced constitutively by *Rhizoctonia solani* (cf. Robson et al. 1989) and by *E. rostratum* (cf. Ortega 1993). It has been reported that *C. gloeosporioides* also produces additional enzymes, such as esterase (Cunningham & Kuiack 1989), endopolygalacturonase (Prusky et al. 1989), amylase (Krause et al. 1991) and cutinase (Sweigard et al. 1992).

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A LATE PLEISTOCENE MAMMAL FAUNA FROM STONEWALL COUNTY, TEXAS

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Abstract.—Fourteen mammalian taxa are identified from a late Pleistocene site in Stonewall County, Texas. Shell from the site has been dated at 13,270 ± 110 YBP. The present ranges of six taxa are used to create an area of sympatry. Environmental and ecological conditions found in the area of sympatry today best represent those at the Tonk Creek site 13,000 YBP. The fauna consists of species typical of a tall-grass prairie with locally mesic conditions. This fossil faunal assemblage from Stonewall County is indicative of the existence of cooler and probably more moist conditions 13,000 years ago than present.

Tonk Creek, a small tributary of the Double Mountain Fork of the Brazos River, begins southwest of Aspermont, Stonewall County, Texas and flows to the east-northeast. Tonk Creek cuts into Pleistocene deposits 6.8 km E of Aspermont and just north of where U.S. Highway 380 intersects with the creek (Fig. 1).

The thickest exposure of these deposits consists of two vertical meters of gray silt embedded with caliche nodules, and small limestone and quartzite pebbles. A 30-40 cm thick layer of caliche tops the deposit, and the base is in contact with Permian red beds. Approximately 907 kg of matrix was removed from the lower meter of the deposit. The fossils which were recovered following the screen-washing of this matrix constitute the Tonk Creek local fauna. Mollusc shell obtained from this matrix was radiocarbon dated at 13,270 ± 110 YBP (Beta Analytic Inc. #50807).

Accounts of Species

Sorex cinereus (masked shrew).—Six partial mandibles of *Sorex cinereus*, one with the condylar area complete, were recovered from the Tonk Creek site. The masked shrew is presently found over much of northern North America and southward along the mountain ranges into Georgia and New Mexico. It is found in a variety of habitats, both grassy and forested, and seems to prefer mesic areas (Jones et al. 1983). This species has been recovered from many Pleistocene sites in northwestern Texas (Dalquest & Schultz 1992).

Spermophilus sp. (ground squirrel).—Several teeth from a small ground squirrel were found, including four upper M1's or M2's, one

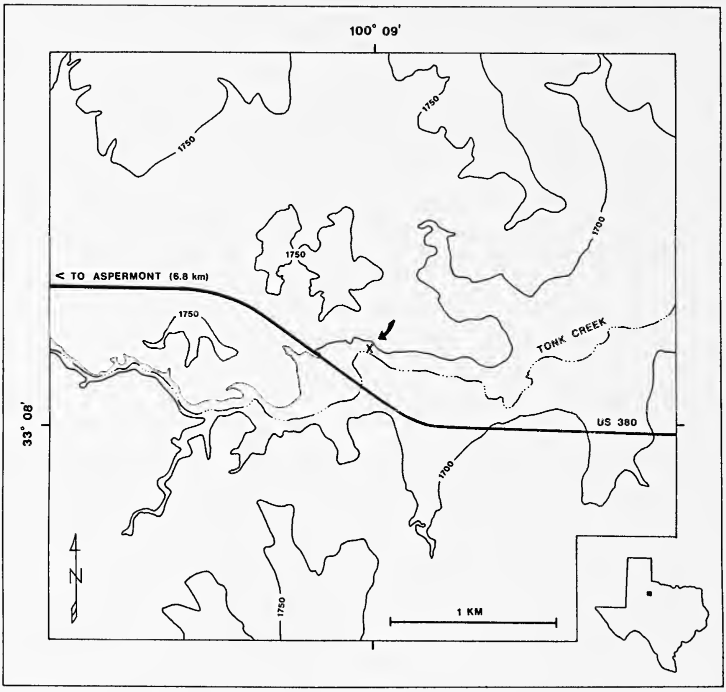

Figure 1. Map illustrating the location of the Tonk Creek local fauna (indicated by an x and arrow). Elevation is given in feet. (From U.S. Geological survey, NW/4 Aspermont 15' quadrangle.)

upper M3, two lower molars, and one lower P4. These teeth are indicative of a ground squirrel the size of *Spermophilus tridecemlineatus* or *S. spilosoma*. Sizes of teeth overlap in these two species, making identification difficult. Both species are found in open grassland environments.

Thomomys sp. (pocket gopher).—An upper P4 and four molars were recovered. Lower P4's are needed for specific identification. Gophers of this genus are distributed throughout much of the western United States and Mexico (Hall 1981). Of the many species of *Thomomys* found in North America, only *T. talpoides* presently occurs with the other species identified from this fauna. Another species, *T. bottae*, can be found as near as the Trans-Pecos region of Texas (Hall 1981). Either species could have been present at this site.

Geomys bursarius (plains pocket gopher).—Several lower P4's, an upper P4, and several grooved incisors were identified. This species of gopher is presently found in most areas of the central United States where grasslands and sandy loam soils occur, and is locally common in Stonewall County today. The plains pocket gopher is usually one of the most abundant mammal fossils found in Pleistocene deposits of this region (Dalquest & Schultz 1992).

Perognathus sp. (pocket mouse).—Two grooved incisors from a small pocket mouse were found but are not identifiable to species. Pocket mice of this genus are most frequently associated with sandy soils and grassland environments. Three species of *Perognathus* can presently be found with the other members identified from this fauna; *Perognathus flavus*, *P. flavescens*, and *P. fasciatus*. Only the former two currently inhabit the vicinity of Stonewall County.

Reithrodontomys sp. (harvest mouse).—One grooved upper incisor and an upper M1 were found at this site. These teeth are the size of *Reithrodontomys*, with the incisor being closest in size to *R. megalotis* of *R. fulvescens*. Harvest mice are typically found in grassy and brushy prairie environments. *Reithrodontomys fulvescens* and *R. montanus* occur in Stonewall County today, and *R. megalotis* can be found immediately west of Stonewall County. *R. fulvescens*, however, is a recent invader from the east (Stangl et al. 1992) and probably did not occur here during the Pleistocene.

Peromyscus sp.—An isolated upper M1 and damaged lower M1 were identified as belonging to a *Peromyscus* sp.. These two molars are slightly larger than typical *P. maniculatus* and are similar in size to those of *P. leucopus*. *P. attwateri* is larger and can be ruled out. The modern fauna of Stonewall County includes *P. leucopus* and *P. maniculatus*, with *P. attwateri* inhabiting the surrounding broken country.

Microtus pennsylvanicus (meadow vole).—Two partial mandibles with lower M1's and 20 isolated lower M1's were identified as *Microtus pennsylvanicus*. This is presently the most widely distributed species of vole in North America (Hall 1981) and is typically associated with damp meadows, marshes, and riparian environments (Jones et al. 1983). The meadow vole is commonly reported from the late Pleistocene of Texas (Dalquest & Schultz 1992).

Microtus cf. *M. ochrogaster* (prairie vole).—Martin (1991) suggested several characters to differentiate between the lower M1's of *Microtus ochrogaster* and *M. pinetorum*. When compared with a series of five specimens of both species from Oklahoma, only two characters proved useful in discriminating between the two taxa. These were the shape of the third buccal reentrant and complexity of the anterior cap. Using these two characters, seven lower M1's from this site more closely resemble *M. ochrogaster* than *M. pinetorum*. *Microtus ochrogaster* favors prairie habitats, while *M. pinetorum* prefers woodland environments. However, both species can be found in grassy areas along the western edge of their range (Caire et al. 1989; Stangl et al. 1992).

Synaptomys cooperi (southern bog lemming).—The southern bog lemming is represented by a single, slightly damaged, upper M3. This species is most often found in mesic situations much like those preferred by *M. pennsylvanicus*. The bog lemming is known from several Pleistocene sites in Texas (Dalquest & Schultz 1992).

Ondatra zibethicus (muskrat).—Several fragmentary molars of the muskrat were found. *Ondatra zibethicus* is a widespread species, and can be found in areas where permanent water is available.

Zapus hudsonius (meadow jumping mouse).—A partial lower jaw with the anterior portion of the M1 can be readily identified as *Zapus hudsonius*. This species can be distinguished from *Z. princeps* by the occlusal pattern of the lower M1. The anteroconid of *Z. hudsonius* is broad and a deep anteromedian fold is present. The anteroconid of *Z. princeps* is small, and the anteromedian fold is absent or, if present, shallow and disappearing with wear (Klingener 1963). The Tonk Creek specimen clearly exhibits the condition found in *Z. hudsonius*. This species prefers lush grasslands, meadows, and especially the thick vegetation found near streams and marshes (Jones et al. 1983). Few fossils of *Zapus* are known from northwest Texas (Dalquest & Schultz 1992). *Zapus hudsonius* occurred at least as far south as Schultze cave in central Texas during the late Pleistocene (Hafner 1993). The nearest populations of *Z. hudsonius* can be found in New Mexico (Hall 1981) and northeastern Oklahoma (Kaspar et al. 1993).

Camelops sp. (camel).—A molar fragment found at this site can only be identified as that of a large camel.

Equus sp. (horse).—Fragments of a single tooth of an extinct horse can not be identified to species.

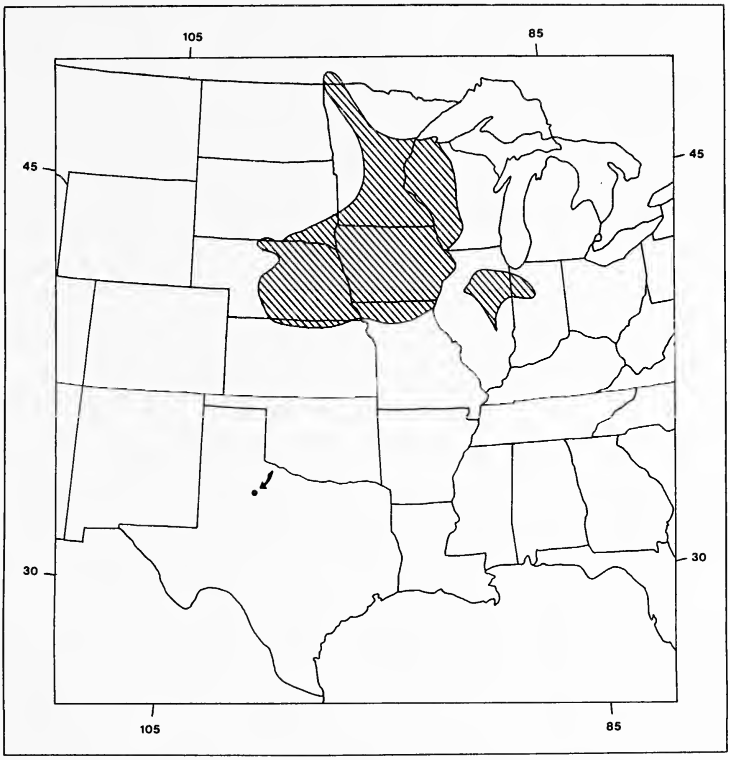

Figure 2. Current area of sympatry for six species of extant mammals recovered from the Tonk Creek local fauna: *Sorex cinereus, Geomys bursarius, Microtus pennsylvanicus, Synaptomys cooperi, Ondatra zibethicus*, and *Zapus hudsonius*. The Tonk Creek site is indicated by a dot and arrow. Ranges from Hall (1981).

Discussion

At least 14 taxa have been identified from the Tonk Creek local fauna. Of these, two are extinct (*Camelops* and *Equus*). Taxa that can be identified to species are *S. cinereus*, *G. bursarius, M. pennsylvanicus, S. cooperi, O. zibethicus,* and *Z. hudsonius*. *G. bursarius* and *O. zibethicus* presently occur in or near Stonewall County, Texas, while the remaining four species are extralimital. Also represented are *Spermophilus, Thomomys, Perognathus, Reithrodontomys, Peromyscus*, and *Microtus* cf. *M. ochrogaster*. Most of the identified taxa are typical of grassland environments.

Ecological conditions which existed during the time that the Tonk Creek fauna was deposited can be inferred from the current distributional range of the extant taxa identified. The present ranges of the six taxa identified to species were used in determining this area of sympatry. It roughly includes eastern Nebraska, Iowa, southeastern Minnesota, western Wisconsin, and central Illinois (Fig. 2). The southern limit is determined by *S. cinereus* and *M. pennsylvanicus*, the north and east by *G. bursarius*, and the west by *S. cooperi*. Most of this area lies within the past distribution of the tall-grass prairie (Shelford 1963).

An estimation of the climate at the location of Tonk Creek local fauna can be made by a comparison of the current climatic conditions in the area of sympatry. While there is a large variation in both the temperature and precipitation of this area, some generalizations can be made. Normal annual precipitation ranges from 20 in. at the western border to almost 40 in. at the eastern border. Average daily temperature for August and January are, respectively, 65° F and 5° F at the northern border, and 77° F and 27° F at the southern border. Present environmental conditions which exist at the Tonk Creek site are as follows: 22 in. normal annual precipitation; 84° F average daily temperature in August; and 42° F in January (Anonymous 1968). Based upon these climatological comparisons, it is determined that the Tonk Creek area must have experienced cooler and moister conditions 13,000 years ago than present in order to facilitate the presence of many of the fossil species recovered from this site.

Acknowledgments

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ABANDONMENT OF HAND-DUG WELLS:
A CASE STUDY IN ELLIS COUNTY, TEXAS

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ABSTRACT.—Wells dug by hand that supply water to homes and villages can be found all over the world. Although many are still in use, others have been abandoned, especially in developed countries. An extensive well inventory in Ellis County, Texas, indicates that 10 percent of 811 hand-dug wells found on farms and at homes or former homesites are still in use. These are generally in good condition, although most do not meet the published requirements of a safe shallow-water supply. The unused wells range in disrepair, typically having open tops and failing well crowns. Many have been used as receptacles for discarded bricks, wire, household trash, and other debris. Leachate from trash in these wells has likely caused local contamination of shallow ground water.

Wells that were dug by hand can be found all over the world and are, or have been, used to supply potable water to households or even small villages. The United States alone has more than 1.6 million hand-dug wells (National Ground Water Information Center), which can often be located by their brick well crowns (Fig. 1). Many developed countries have abandoned hand-dug wells in favor of wells that can tap ground water from deeper aquifers or treated surface water. Many of these abandoned wells have been improperly sealed and have therefore become a safety concern. Open well bores are not only a physical hazard, but also a potential pathway of shallow ground-water contamination.

An intensive well inventory was undertaken in North-Central Texas as part of a hydrogeologic characterization of the Superconducting Super Collider (SSC) site. Results from this survey showed that most hand-dug wells in the area were abandoned and remain improperly sealed and uncovered. Wellhead conditions have created a public hazard to people and livestock. Many well owners have filled their wells with debris and household garbage. Leachate from these wells may locally contaminate shallow ground water and nearby springs or streams.

Historical Background

Water is necessary to human existence. During prehistory, human activity centered around streams, springs, and other sources of fresh water. Humans eventually discovered that ground water could be obtained by digging at an appropriate location. Perhaps they learned

Figure 1. Brick well-crown of a hand-dug well in Ellis County, Texas.

this by observing animals such as the coyote digging in dry stream beds to find water (Meinzer 1934).

Whereas evidence of the earliest hand-dug wells can be found in Mesopotamia from 6000 B.C. (Miller 1982), the oldest known hand dug well existing today is located in Pakistan and is dated at 3000 B.C. (Bromehead 1942). Many early wells were shallow, probably extending no more than 3 m into unconsolidated material, but some wells were sunk farther into the ground to reach a deeper water source. One impressive excavation is Joseph's well near Cairo, Egypt (Johnson, 1966). Dug into solid rock, the well is nearly 91.5 m deep. Another large well is located in Greensburg, Kansas. Dug in the 1880's, this well is 9.8 m across and 33.2 m deep (Zwingle 1993).

Because many wells were dug in unconsolidated materials such as glacial or alluvial deposits, hand tools were all that were required to dig the wells. Casing needed to be placed carefully to prevent well collapse and personal injury, especially in wells of great depth (Watt & Wood 1976; DHV 1979). Well digging in consolidated rock such as granite, basalt, or limestone presented a more laborious challenge in removing material and probably was attempted only after the development of metal tools. Hammers and wedges were traditionally used to sink wells into hard rock. Another method involved building a fire on the rock surface and then dousing the area with cold water, which caused the rock to craze in response to the abrupt temperature change (Watt & Wood 1976; Hardcastle 1987). Explosives offered an easier method of breaking up the rock. More recently, compressed-air tools such as jackhammers and specially designed augers have been used to sink large-diameter, shallow wells into consolidated rock.

Dug wells are typically 1 to 1.3 m in diameter: large enough to accommodate one or two people digging. Wells in hard rock commonly have larger diameters for storage. For instance, wells dug in crystalline rock in India have diameters as great as 10 m. These wells collect and store rain water during the dry season and serve as production wells during the wet season (Watt & Wood 1976). Large-diameter wells provide useful ground-water storage from low-permeability aquifers.

Wells in shallow aquifers are typically dug during the dry season. During this time, water levels are at a lowstand and well diggers need not worry about ground-water inflow. When pumps are available, they are used to lower water levels to accommodate the well diggers. These wells can be deepened if they go dry at a later date.

In areas of low permeability and poor water quality, cisterns are constructed instead of wells. Cisterns are used to collect rainfall and store water. Their construction differs from wells in that the inner surface of the excavation is sealed to prevent water from leaking out of the excavation. Some hand-dug wells constructed in hard rock behave as cisterns during the dry season because of low permeabilities in the lower portion of the wells. Mace & Dutton (1994) showed that permeability can decrease over an order of magnitude with depth in the weathered zone in chalk. During dry periods, water was hauled to and stored in some of these wells. Because the water leaked out of the wells slowly, the wells were effectively cisterns.

Even in early times, people realized wells needed to be maintained properly to ensure a safe water supply. For instance, covered wells are reported in the Bible, and wells constructed in early Arabia, Britain, Finland, and the Orient show evidence of wellhead protection

(Hardcastle 1987). In modern times, many authors and agencies have addressed dug-well placement, construction, servicing, and destruction (Todd 1959; Texas State Department of Health 1970; Environmental Protection Agency 1975). However, little public education, enforcement, or incentive ensures compliance with safe well design, upkeep, or destruction.

The first wells in North America were hand dug by Native Americans. In the western and southwestern United States, wells and cisterns constructed by Native Americans are located in Utah, Colorado, Arizona, New Mexico, and Texas (Toulouse 1945; Evans 1951; Wheat 1952; Crown 1987). Native Americans dug numerous wells at Mustang Springs north of Midland, Texas, during a long drought around 4600 B.C. (Meltzer 1991).

Most hand-dug wells in the United States, however, were constructed after European settlers came to North America. As settlement moved west, wells were dug at new towns and homesteads to supply water to households and livestock. Major settlement began in Ellis County, Texas, around 1839 after the Native American population had been forcibly driven from the area (D. Jurney, pers. comm.). Initial settlement centered about the Red Oak Creek area near present-day Ovilla, Texas, and later spread to the mesquite-covered prairie near the Trinity River and Chambers and Richland Creeks. In the 1850's, settlement spread to springs near the present towns of Bethel, Boz, and Maypearl. Settlement slowed during the Civil War but grew quickly after the war, the landscape becoming dotted by farms. Because neither springs nor surface water could provide a convenient water supply to farmers who settled on upland prairies, wells were dug in limestone and alluvium. Many of the dug wells in the area date from 1850 to 1930 (D. Jurney, pers. comm.).

After the 1930's, deeper wells were more commonly drilled into regional sandstone aquifers at depths of 250 to 600 m below ground surface. Then, as water-supply districts expanded into rural areas, dug-wells became less important as sources of potable water. Large diameter shallow wells, however, have been used in Ellis County since 1930. Many have been recently constructed by means of homemade 1 m diameter mechanical augers.

Construction of a Hand-Dug Well in Ellis County

David C. Paul grew up in Ellis County and worked on his father's farm, which currently lies on the west campus of the SSC. His unpublished memoirs provide a detailed description of using pick and powder to sink a well in the Austin Chalk during the fall of 1939 or 1940. Pick, shovel, auger, windlass, black blasting powder, and fuse were the main tools used in constructing the well. The initial well location was decided by means of a water witch and a divining rod, but after digging 6 m and not reaching water, Paul's father arbitrarily decided on the well's present location. Well sinking consisted of five stages: (1) digging through the soil horizon, (2) breaking through the highly weathered zone, (3) blasting through the consolidated rock, (4) constructing the well curb and pump platform, and (5) placing the pump. A pick and shovel were used to clear the soil from the well site. The ground was loosened in a 1.5-m-diameter circle and removed until weathered chalk was reached. The chalk could be removed using a pick and shovel, too, although it took more effort. About 1 m into the ground, solid rock was encountered. At this point, the well radius was reduced about 0.1 m to provide a ledge on which to rest the well curb. Paul and his uncle used blasting powder to remove the solid rock:

> "To set off an effective charge, I drilled a hole in the solid rock about eighteen inches deep, frequently removing the auger from the hole so as to keep the hole clear of rock debris. This auguring required about twenty to thirty minutes of very hard work. When I reached the desired depth, Uncle Roy sent down the powder, some fuse, and some newspaper. I used about one and one half cupfuls of powder. First I poured about half or less of the powder in the hole I had drilled, and then I inserted the end of a two foot section of fuse, poured in the remaining powder and stuffed in a wad of newspaper. Then with an iron bar, I tamped rock dust and debris in around the fuse a little bit at a time until it was full. The wad of newspaper was to keep the powder from being mixed with the rock dust and debris. Tamping in the debris was to confine the blast to the rock mass rather than have it blow out through the hole I had drilled with the auger."

Charges were placed in the floor near the wall. Paul's uncle lifted him from the well bore via rope and bucket and retreated a safe distance. After blasting, rock dust and powder smoke needed to be removed from the well cavity, which was accomplished by means of wagon sheets:

> "By common sense we knew better than to go back down into the well while the rock dust and powder smoke were still present. It would linger for a long time unless we forced it out. We had an

> ingenious way of getting it out. We held a wagon sheet down into the well. This sheet was about fourteen by six feet, and after the well got deeper we fastened two of them together end to end. We held it so that three or four feet of it was above ground. We turned the side of it to the wind, and if there was even as much as a slight zephyr, this technique cleared the well of bad air in no time at all."

Rock debris was cleared and another charge placed and detonated. Paul recalls blasting and digging into the chalk 0.5 to 1.0 m per day. The rope and rock bucket were used as a plumb to ensure that the well shaft was sank linearly. Paul and his uncle stopped digging without reaching water and felt great disappointment after such an exertion:

> "This was an emotion producing occasion - as if we had a chance to get water and missed it through no fault of our own. There was a loss of hope and expectation. Why go on digging? Why not call the whole thing off? We continued to dig for a day or two more. Maybe we would yet find water. Finally, at a depth of twenty-seven or thirty feet, we quit. I never went down to the bottom of that well again."

However, the well had been dug during a dry period. Once winter rains arrived and the water table rose, their effort was rewarded by a well full of water. After they realized the well would produce water, they constructed a brick curb and an engine platform at the well. The well never went dry during the subsequent 12 to 15 years.

Site Geology

Shallow ground water in Ellis County is found beneath the weathered outcrops of the Austin Chalk and Taylor Marl and in overlying Quaternary and Pleistocene alluvium (Fig. 2). The Austin Chalk consists of alternating fine-grained chalk and marl beds deposited in a marine deep-water platform environment. The lower Taylor Marl is a fine-grained marl, calcareous mudstone, and shale deposited in a marine-shelf environment. The Quaternary and Pleistocene alluvium consists primarily of unconsolidated, stratified clay, sand, granules, and pebbles composed primarily of carbonate-rock fragments. The alluvium can be as thick as 14 m.

The chalk and marl are weathered and fractured near land surface with many fractures in these weathered strata possibly resulting from unloading processes that caused bedding-plane separation. These

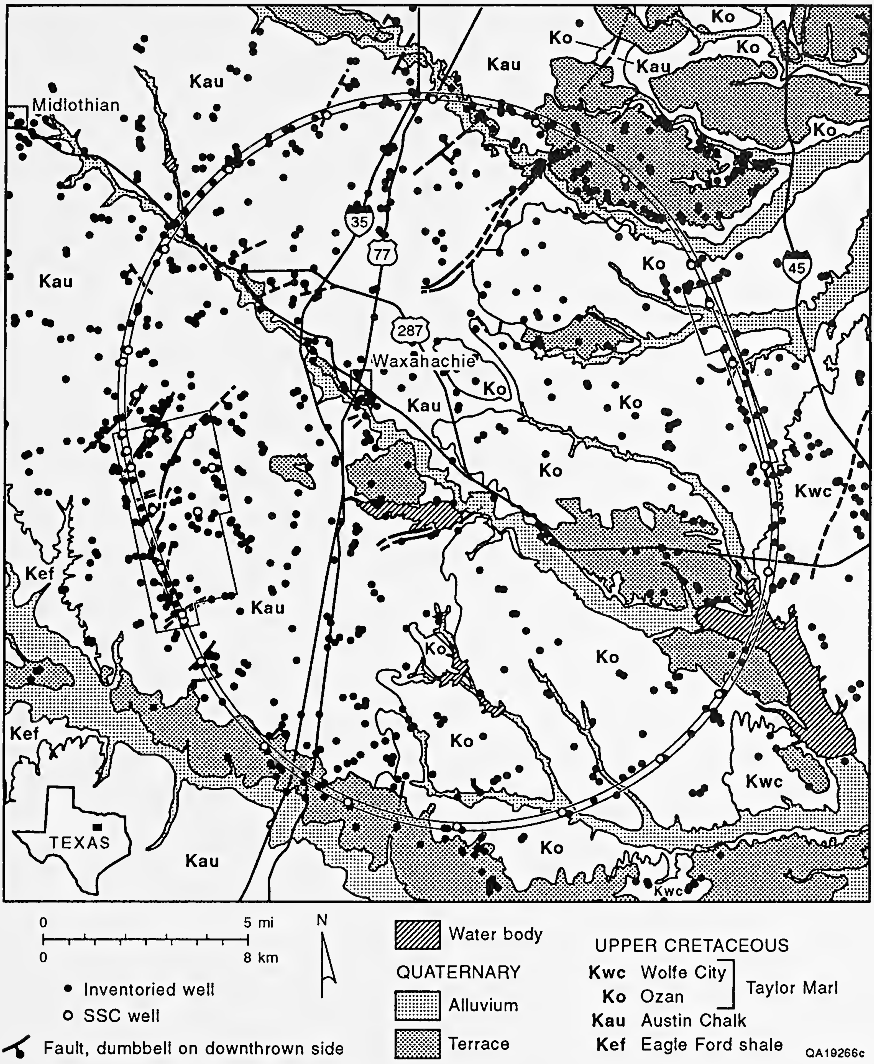

Figure 2. Geologic map of part of Ellis County in North-Central Texas; SSC project area outlined. Black dots show wells inventoried during study.

fractures commonly have millimeter-scale apertures and are not healed by mineral fillings, although many joint surfaces have been coated by hematite (Collins et al. 1992). Bedding-plane separations connect vertical fractures and lead to higher permeabilities. Mean thickness of the weathered chalk is 3.6 m and locally as thick as 14 m (Collins et al. 1992).

Characteristics of Ellis County Dug Wells

Distribution.—The distribution of hand-dug wells was determined by means of a field survey of private property near the Superconducting Super Collider (SSC). An exhaustive evaluation of well location and density was conducted over 1,200 contiguous pieces of property in Ellis County of which land or subsurface rights had been purchased for the SSC. A less exhaustive survey was undertaken inside and outside the SSC site. If possible, physical measurements and descriptive notes were recorded of well radius, well depth, casing height, geologic formation, casing design and composition, condition of the wellhead, and use of the well. Results from a well survey conducted at an alluvial deposit in the northeast part of the county (Dutton & Wickham 1992) were included in a data base of the entire county.

A total of 811 hand-dug wells were located in Ellis County (Fig. 2), 390 in chalk, 169 in marl, and 171 in alluvium. A thorough well inventory was performed on the SSC's West Campus in the Austin Chalk on the west side of the county (the boxed-in area on the left side of Fig. 2). A total of 108 wells were located on this property, corresponding to a density of 3.5 wells per square kilometer. If this area can be considered representative of well density in Ellis County, more than 4,300 wells might be located in the 1,230 km^2 in Figure 2. A well inventory in the terrace deposit in the northeast part of the SSC site indicates a well density of 2.8 wells per square kilometer (Dutton & Wickham 1992). These well densities are conservative estimates because many wells reportedly have been filled, their locations now unknown.

In the area of the West Campus, there appears to be an increased well density near major faults. Faulted areas tend to be more intensely fractured and thus have greater permeabilities. Yelderman et al. (1988) noted how structure and weathering affected ground-water flow in shallow ground-water systems in chalk and marl. Barquest (1989) found that areas adjacent to faults in the Austin Chalk had much higher fracture intensity and weathering, particularly in the downthrown block. Bradley (1993) noted that well density was higher in areas of greater fracture density in the Lake Waco Formation.

Well Design.—Thorough measurements of well radius, well depth, casing height, geologic formation, casing design and composition, condition of the wellhead, and use of the well were made at 362 of the shallow wells. The average depth of these wells is approximately 6.83

m, ranging from 1.52 to 15.24 m. The well depths are likely correlated to weathered zone thickness. Interviews with several landowners revealed that their wells were dug until "blue rock", or unweathered chalk, was reached. Barquest (1989) noted that well depth was related to weathered zone thickness in the Austin Chalk of Central Texas. Bradley (1993) noted a similar relation in the Lake Waco Formation of Central Texas. The average borehole diameter at the surface is 0.88 m, ranging from 0.18 to 4.27 m. All but two wells have circular boreholes. One well in chalk has a square, 1.2 by 1.2 m borehole and the appearance of a mine shaft. Dimensions of the other well are 4.3 by 4.3 m, and it has a cement crown and railroad-tie well screen. Among the wells having circular cross sections, variation in quality of workmanship was evident from approximately circular, roughly hewn walls to perfectly rounded, smooth walls.

Hand-dug wells characteristically have large diameters owing to construction techniques. The well radius has to be large enough for an individual to operate a shovel or pick in excavating the well. Well diameters in many hand-dug wells in the Austin Chalk widen with increasing depth. This widening of the well bore increases the number of fractures intersected, the effective radius, and the storage capacity of the well, thus increasing the usefulness of the well. In local parlance, these wells are referred to as "jug" wells because their shape resembles a narrow-necked jug.

Well radius with depth can be calculated by pumping all the water from a well while measuring water levels over time. If the pumping rate is known, drawdown is measured with time (ground-water inflow from the formation being inconsequential), and if the borehole is circular, then the radius of the well, r_w, at a depth z is

$$r_w = \sqrt{\frac{Q \, \Delta t}{\pi \, \Delta d}}$$

where r_w is the radius of well at depth d, Q is the pumping rate, Δt is the change in time, and Δd is the change in head in well over Δt. In this manner, well radius with depth can be found and plotted.

A total of 42 hand-dug wells were purged to determine well radius with depth. The 32 wells in chalk can be grouped into four shapes (Fig. 3): jug, conical, shaft, and miscellaneous. Jug wells have a narrow, straight neck near land surface that widens at depth to another constant radius (Fig. 3a). Conical wells have a narrow neck near ground surface

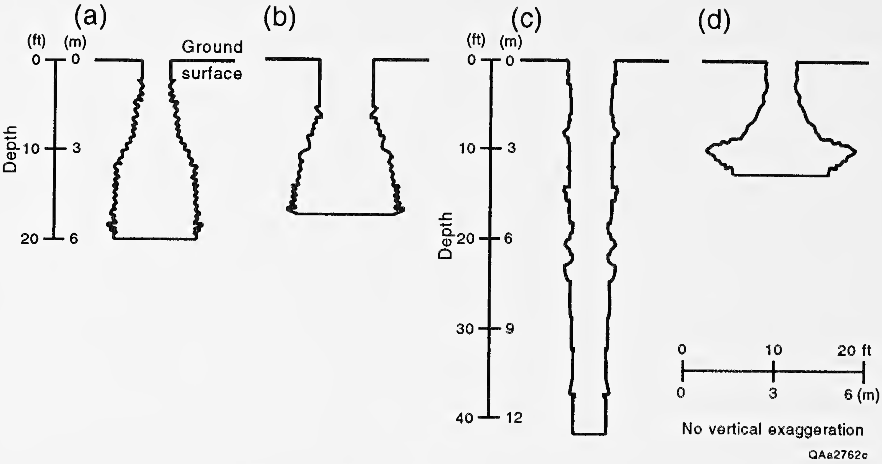

Figure 3. Different geometries of wells in chalk, which were determined by pumping the well bore.

that widens with depth at a constant slope to the flat well bottom (Fig. 3b). Shaft wells have the simplest shape, their radius remaining constant with depth (Fig. 3c). A variety of shapes are grouped in the fourth category. For example, telescoping shaft wells that were deepened, with a diameter different than that at the top, and wells resembling the profile of a Middle Eastern lamp (Fig. 3d). Some of the dug wells were deepened to tap deeper ground water during droughts, such as those redug during the drought of 1952 and 1953, which caused the water table to fall below the base of shallow wells.

Typical design of Austin Chalk wells includes a brick collar extending 0.9 to 1.8 m through the soil horizon to the top of the chalk, the exposed chalk composing the remainder of the well depth. Some wells have collars constructed of cement or mortared pieces of chalk, whereas a few others are collarless.

Wells in the alluvium generally have a uniform radius and are cased in unmortared brick at depth. Smaller-diameter wells are cased in plastic or steel pipe, having been dug more recently. Wells in the marl are typically of constant radius. The walls and floors of many well bores in the marl were completely sealed by cement in an attempt to prevent poor-tasting "gyp" (that is, gypsum or sulfate-rich) ground water from seeping into the borehole. These cisterns stored rainwater collected from the nearby roof of a home or barn. Barrett (1988) found areas of wells and areas of cisterns in the marl near West and Lorena Texas and attributed these areas to different flow systems. The greater incidence of wells in Barrett's (1988) study area may be related to a higher intensity of faulting. Several wells in chalk also were used as cisterns during droughts with water being carried from nearby streams and springs. Some wells in chalk had water directed to them from rooftops to complement groundwater seepage to the well.

Past and Present Uses.—Most wells were dug to meet domestic and livestock water needs and were probably not used for irrigation because of low yields. Water consumption in homes without indoor plumbing probably was about 37.9 liters/day per person (Texas State Department of Health 1970), which most dug wells could easily supply. In comparison, average present-day water consumption at households in municipal areas is between 1,733 and 2,619 liters/day (Driscoll 1986). These usage rates include as much (or more) water for lawn watering as for household consumption. A well dug in Lone Elm in the west part of Ellis County was reportedly a municipal supply well for the small town. This well had an unusually high specific capacity (58 liters/min per meter of drawdown).

In times of drought, water was carried from nearby streams, springs, or viable wells and deposited into the borehole (R. E. Davis, & D. C. Paul, pers. comm.). In this manner many wells dug in chalk were used as cisterns. A particularly severe drought that caused the drying of many dug wells occurred from 1952 through 1953. Currently, most hand-dug wells are unused or abandoned. Only 82 wells (10 percent of total inventoried) are currently being used; 45 of which are used in drinking, cooking, or washing. These wells are generally in good condition, although most do not meet all the requirements of a safe shallow-water supply as determined by the Texas State Department of Health (1970:17), such as:

- well should be protected by a watertight, insect-proof seal,
- surface water should be drained away from the wellhead,
- surface casing should be used to prevent polluted water from seeping into the well, and
- good well construction should prevent the growth of aquatic vegetation that might impart objectionable odors and tastes to well water.

Many hand-dug wells have inadequate well covers that do not prevent surface water from running into well bores. Shallow wells in chalk are particularly susceptible to contamination because they tap into shallow, unconfined, fractured aquifers, which are noted for rapid recharge and accelerated contaminant transport.

Abandoned wells range in condition. Many wells near homes have been sealed to prevent children or pets from falling into well bores, although many others remain unsealed. Numerous other wells vary in disrepair, having collapsed or partially collapsed well crowns and open tops. Landowners spoke of livestock and wild animals falling into wells and tractors getting stuck in old well bores. During early winter months, rats have been observed floating in many unprotected dug wells, apparently attracted to the warmth emanating from the borehole. Other wells have been or are being used in the disposal of household trash, bricks, wire, automobile tires, and roofing shingles. One well had a small automobile in its mouth, and another contained a kitchen sink.

Because of rapid recharge and high ground-water-flow rates, alluvial and weathered bedrock aquifers are susceptible to contamination through these wells. Ground-water contamination has probably been caused by these wells, but no clear cases have been recorded. Dutton & Wickham (1992) reported that all wells in the alluvial aquifer in the northeast part of the county show some coliform bacteria levels above Texas Department of Health standards for drinking water. Seven hand-dug wells in the Austin Chalk also show some level of coliform bacteria. Whether these results reflect only endemic bacterial populations in the large-diameter wells or contamination throughout the aquifer was undetermined.

Conclusions

An extensive well inventory in Ellis County, Texas, revealed that a total of 811 hand-dug wells still exist on farms and at homes or former homesites, most dating from 1860 through 1930. The average depth of these wells is 6.83 m, ranging from 1.52 to 15.24 m. Average borehole diameter at the ground surface was found to be 0.88 m, ranging from 0.18 to 4.27 m. Wells in the chalk were typically designed with a brick collar extending 0.9 to 1.8 m into the overlying soil and heavily weathered chalk. The remaining depth of the well was commonly left uncased, generally increasing in diameter with depth. Wells in marl and alluvium were encased in brick throughout. Wells in marl typically had a larger diameter than did wells in alluvium. Boreholes in marl were commonly sealed to prevent bad water from entering the well. These boreholes stored water collected from nearby rooftops.

Dug originally to supply water to household and farm, most wells are currently abandoned and ranging in disrepair. Only 10 percent of these hand-dug wells are still in use, and only half of these are used for drinking, cooking, or washing. They are generally in good condition, although most do not meet published requirements of a safe shallow-water supply because the wellheads were improperly constructed or the well is too close to a potential source of contamination. Many wells near homes have been sealed to prevent children or animals from falling into well bores, but many others have been improperly sealed. Other wells have been used as receptacles for unwanted bricks, wire, household trash, and other waste material. Unfortunately, the use of these wells as trash containers has probably caused and will continue to cause local contamination of shallow ground water.

Acknowledgments

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FIRST RECORD OF *APLYSIA CERVINA* (DALL & SIMPSON) (GASTROPODA: OPISTHOBRANCHIA) FROM THE TEXAS COAST

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Abstract.— The sea hare *Aplysia cervina* (Dall & Simpson) is reported for the first time from the south Texas coast. The occurrence of this species in the waters of the western Gulf of Mexico is discussed relative to its currently known distribution.

On 3 November 1990, 20 specimens of the sea hare *Aplysia cervina* were collected from the south Laguna Madre at South Padre Island, Texas. They were taken from mud flats along the west coast of the island approximately 400 m south of the Coast Guard Station during an early morning low tide. There was an equally large number of the common mottled sea hare *Aplysia brasiliana* Rang present in the collections. A second trip to South Padre Island was made on 15 December 1990 to secure additional specimens. Collections were made near midnight during a period of relatively high tide. Five specimens were taken from among granite boulders which line the channel of the Brazos Santiago Pass at the southwestern tip of the island.

The following sea hare is added to those species reported by Strenth & Blankenship (1977) and Andrews (1992) as occurring in the coastal waters of south Texas. Voucher specimens are deposited with the holdings of the Philadelphia Academy of Natural Sciences (ANSP) and the Houston Museum of Natural Science (HMNS).

Aplysia cervina (Dall & Simpson 1901)

Tethys cervina.— Dall & Simpson 1901: 365.

Aplysia cervina.— Eales 1957: 246; 1960: 299.— Marcus & Marcus 1959: 3.

Type-locality.— Puerto Rico.

Material Examined.— South Padre Island, Cameron County, Texas, U.S.A., 3 November 1990, coll. N. E. Strenth. Three specimens (ANSP A18296), two specimens (HMNS 34566).

Remarks.— Living specimens ranged in weight from 39 to 124 g. Due to its similar size and color, *Aplysia cervina* can easily be mistaken

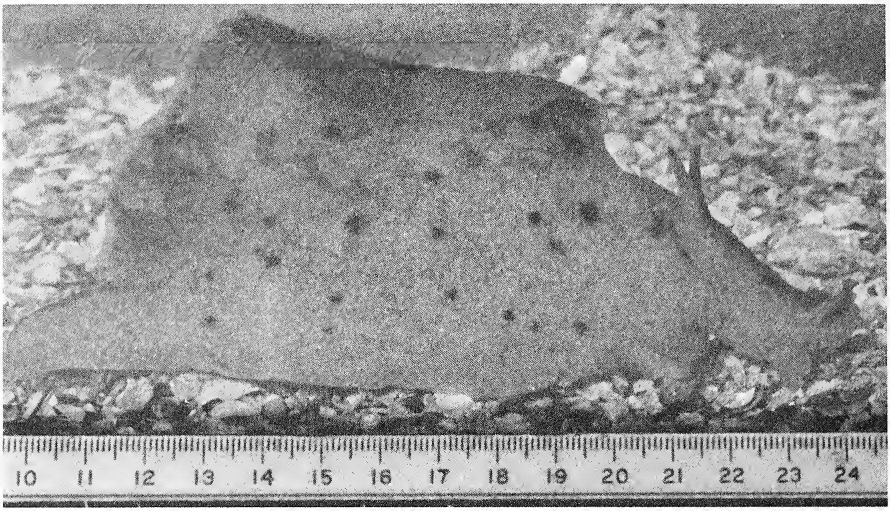

Figure 1. *Aplysia cervina* (Dall & Simpson) from South Padre Island, Texas. Weight of specimen 80 g. Scale in cm.

in the field for the more common *A. brasiliana*. Positive identification of specimens can be made by the presence of "smoky brown spots" (Eales 1960:300) on the sides of the body (Fig. 1). These may number as high as 30 per side according to Eales. This is in marked contrast to the more mottled appearance of *A. brasiliana*. Further confirmation of positive identification is provided by the presence of a short broad flattened penis; this structure is long and tapering in *A. brasiliana*. Due to the overlapping of numbers of teeth, radula formulae are of little value in distinguishing this species from *A. brasiliana*. *Aplysia cervina* ranges from 22.1.22 to 40.1.40 (Eales 1960) and *A. brasiliana* from 29.1.29 to 51.1.51 (Strenth & Blankenship 1978a). The numbers of rows of radula teeth do, however, vary somewhat in mature specimens of these two species. *Aplysia cervina* ranges from 38 to 48 (Eales 1960) and *A. brasiliana* from 50 to 70 (Strenth & Blankenship 1978a). The largest specimens of *A. cervina* collected during this study from the south Laguna Madre ranged from 41 to 44 rows of radula teeth. This is well within the range of this species and provides concluding evidence as to the positive identity of this sea hare.

Feeding habits.— There is some contradiction in the literature relative to the reported feeding habits of *Aplysia cervina*. Marcus & Marcus (1959) noted the pronounced presence of red algae in the digestive tract of a single specimen of this species from the Brazilian coast. In a study conducted along the northern coast of Columbia, Bandel (1976:97) later reported that *A. cervina* was "kept over long periods on a diet of filamentous green algae". During the collection trip of 15 December 1990, specimens of *A. cervina* were observed to be actively moving about and feeding upon the green alga *Enteromorpha.* While observations made during the course of this study appear to corroborate the findings of Bandel (1976), it is possible that *A. cervina* exhibits a broad feeding range for species of both red and green algae. Only additional studies can determine the overall feeding preference of this species of sea hare. Specimens of *A. cervina* would not feed upon the commercially dried red seaweed "Laver" (*Porphyra* spp.) which is commonly used to maintain specimens of *A. brasiliana* in the laboratory (Strenth & Blankenship 1978b).

Occurrence.— It appears that the presence of *Aplysia cervina* along the south Texas coast may be both a sporadic as well as seasonally influenced event. This type of occurrence is not uncommon for sea hares and was reported by Strenth & Blankenship (1977) for both *Aplysia dactylomela* Rang and *Aplysia morio* Verrill from the south Texas coast. Because of its similar size and appearance to *A. brasiliana*, it is possible that small numbers of *A. cervina* may have gone unnoticed in the field by earlier collectors. This species was not, however, noted to be present at South Padre Island during extensive field studies conducted on *A. brasiliana* from 1975 through 1978 (Strenth & Blankenship 1991). Only continued field studies can determine the nature of the occurrence of this sea hare along the south Texas coast.

Distribution.— Although this report represents the first published record of this species for the Texas coast, its presence at South Padre Island is not inconsistent with its previously known distribution. The range of *Aplysia cervina* was given by Eales (1960:299) as the "Atlantic seaboard from Eastern U.S.A., through Central America and the West Indies to Brazil". While the only known United States specimen record is from Charleston, South Carolina (Eales 1957), it has been reported as close to the Texas coast as the Yucatan Peninsula of Mexico (Eales 1960). This record extends its known distribution into the western Gulf of Mexico.

Acknowledgements

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GENERAL NOTES

A BROWN TREE SNAKE (COLUBRIDAE: *BOIGA IRREGULARIS*) SIGHTING IN TEXAS

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Following the establishment of *Boiga irregularis* on Guam (Mariana Islands), presumably in the late 1940's, this snake has become a significant economic, biological, and human safety problem (Fritts 1988). Due to predation by this snake, virtually the entire native forest-dwelling avifauna has been extirpated (Savidge 1987) and the lizard community has been substantially altered (Rodda & Fritts 1992). By 1993, at least 900 localized and several island-wide power failures were attributed to the snake's nocturnal and arboreal habits (Fritts et al. 1987). Considerable economic impact was also estimated due to predation on domesticated animals (Fritts & McCoid 1991). Despite this rear-fanged snake's characterization as mildly venomous, some reported bites have been medically significant (Fritts et al. 1990; 1994). Compounding these problems on Guam is a tendency, due to high densities (Rodda et al. 1992) and proximity to shipping facilities, to infest air and surface traffic originating at or transiting Guam. These records of dispersal via air and ship traffic include: Oahu in the State of Hawaii, Saipan, Tinian, and Rota in the Mariana Islands, Kwajalein in the Marshall Islands, Diego Garcia in the Indian Ocean, Okinawa in the Ryukyu Islands, Cocos Island south of Guam, and Wake Island in the central Pacific Ocean (Fritts 1987; 1988; McCoid & Stinson 1991). Only the incident on Wake is not directly attributable to the Guam infestation. Because of the number of *B. irregularis* sightings (19), it is likely that a recently established incipient population exists on Saipan.

This report represents the first documented case of *B. irregularis* on the mainland United States. On 12 May 1993, crated household goods that had arrived from Guam were unpacked at Ingleside Naval Station which is located on the north side of Corpus Christi Bay, Aransas County, Texas. A military customs inspector and the owner of the household goods were present during the unpacking and they reported that as paper wrapping material was removed from the crate, a live (estimated total length 0.6 - 0.9 m) snake fell to the parking lot. As the snake was attempting to crawl away, one of the moving company personnel decapitated it with a prybar. Because of his familiarity with the snake while stationed on Guam, it was positively identified by the owner of the household goods as a brown tree snake, *B. irregularis*. Unfortunately, the carcass was discarded and the specimen not recovered.

Transit events to neighboring islands from Guam probably measure in terms of hours (air traffic) or weeks (surface traffic). The incident reported here began in October 1992 when the household goods were packed. The goods arrived in Texas in December 1992 and were unpacked in May 1993, spanning a period of seven months. Despite the apparent absence of water and prey, this specimen was able to survive in a sealed crate for a considerable period of time. Due to the fact that the snake arrived alive, it is assumed that the crate was protected from extremes in temperature. It is possible, however, since gekkonid and scincid lizards are ubiquitous and abundant on Guam, that these snake prey species were also inadvertently packed in the crate. Egg shards of both *Hemidactylus frenatus* and *Lepidodactylus lugubris* and a dead *Carlia cf. fusca* have been noted to be present in crated personal household goods upon their return to the U.S. mainland from Guam. This incident strongly underscores problems associated with control and containment of this deleterious pest.

Due to the increase of the above dispersal events, civilian and military authorities on Guam have become increasingly aware of the need to interdict *B. irregularis*. Both Guam Customs and Military Customs Inspection training programs now include sections dealing with brown tree snakes and problems associated with infestation. In 1993, the U.S. Department of Agriculture (Animal Damage Control) established a snake interdiction program in both civilian and military port facilities on Guam. Despite these heightened efforts, dispersal events are likely to continue to occur. Standard procedures when packing military household goods on Guam is to place all materials within a large wooden crate, close the crate with nails, secure the crate with metal straps, and caulk all open seams and holes on the crate. A military customs inspector should be present during packing to assure these procedure are followed and to inspect goods for contraband and other prohibited materials (such as brown tree snakes). Due to the fact that the crate arrived in Texas with metal banks and caulking intact, it is assumed that inspection procedures on Guam were partially ineffective. The *B. irregularis* sighting in Texas has led local military customs officials to take extra precautions when inspecting incoming household goods from Guam. There is an estimated average of one military transfer per month from Guam to the Corpus Christi area (C. Wilson, U. S. Navy Corpus Christi Household Services, pers. comm.).

Due to the fact that *B. irregularis* has been shown to be responsible for an array of damages on Guam and has a history of hitch-hiking to neighboring islands, this species was declared as Injurious Wildlife (Federal Register 55(80):17439-17441) in 1990. Transportation of live *B. irregularis* and/or viable eggs, without permit, in U.S. flagged areas is now illegal. The Government of Guam also prohibits the local harboring of this species as a pet.

There is currently no means to estimate the numbers of *B. irregularis* transported to neighboring islands or mainland situations that are not detected, intercepted, and reported. It is clear, however, that the risk of infestation is significantly increased by the volume of traffic from Guam to specific geographic points. It is also important to realize that the most equable climate for *B. irregularis* on the U. S. mainland, in terms of temperature and rainfall regimes, is the Gulf of Mexico coast and Florida.

Acknowledgments

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A NEW RECORD FOR *PLECOTUS RAFINESQUII* (CHIROPTERA: VESPERTILIONIDAE) FROM EAST TEXAS

Monte Thies
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Huntsville, Texas 77341

On the evening of 7 September 1993, an adult male Rafinisque's big-eared bat, *Plecotus rafinesquii*, was captured in a mist net at the Texas Parks and Wildlife Department (TPWD) inactive fish hatchery in Huntsville, Walker County, Texas. This capture represents a new county record for Texas and perhaps more importantly, the first record for this species in Texas since 1986.

This specimen was netted at approximately 2100 hours as it emerged from a 75 cm diameter concrete culvert which was once used to feed water to the hatchery's ponds. The dam providing water to the hatchery broke in 1985 and the culvert has remained relatively dry since that time. Native vegetation including small trees have grown up around the culvert's opening. Identification of the specimen was based primarily upon the size of the ear and color of the abdominal pelage. Although no measurements were taken of the individual, it's testes were noted to be fully descended. This is consistent with Jones' (1977) and Schmidly's (1989) statements that breeding probably occurs in the fall and winter. Due to the fact that this species has been designated as threatened by the TPWD since 1977, it was photographed to document the capture and released the same evening at the hatchery. Identification has been confirmed by Dr. J. C. Turner (SHSU Dept. Biological Sciences) based upon these photographs. No other species of bat were netted nor observed to emerge from the culvert opening.

Previous captures of *P. rafinesquii* have been recorded from nine counties in East Texas: Marion, Harrison, Nacogdoches, Sabine, Newton, Polk, Harris, Jefferson, and Hardin (Schmidly 1989). Two additional specimens, a female from Houston, Harris Co. (11 September 1984), and a male from Beaumont, Jefferson Co. (13 September 1986), were identified for the Texas Department of Health by personnel from the Texas Cooperative Wildlife Collection (TCWC), Texas A&M University, (G. Baumgartner, pers. comm.). All captures have occurred during the months of April through December, with no records for January through March.

Much of what is assumed relative to the biology of this species is based upon inferences from what is known of a closely related species, *P. townsendi*. Although *P. rafinesquii* hibernates in caves and mines in the northern parts of its range (Jones 1977), it is unknown whether this species hibernates in east Texas or migrates to other areas. It appears to prefer pine/oak, juniper, loblolly pine, and long-leaf pine vegetation and partially lighted, unoccupied buildings and other man-made structures such as wells and cisterns for roosting sites. It is assumed to feed on small, flying insects (Barbour & Davis 1969; Jones 1977). Due to the paucity of information available, additional research is needed to determine this species' distribution, abundance, and natural history in east Texas.

I wish to thank B. Dunlap, N. Greenlee, L. Hyler, A. Moldenhauer, and C. Prater for assistance with mistnetting at the fish hatchery and Jack Turner for verification of species identification.

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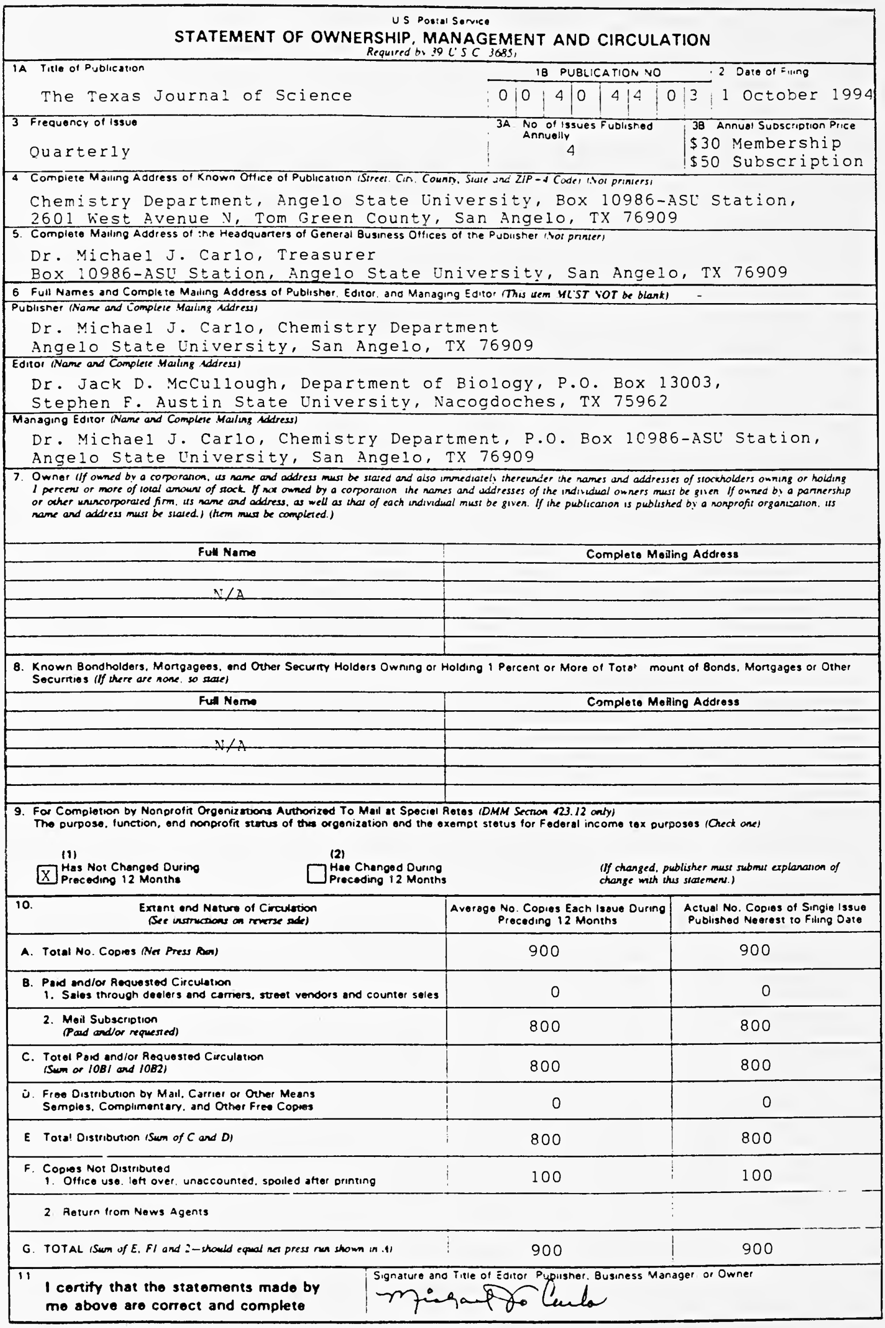

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