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A REVIEW OF SPECIES NAMES FOR
AMMONIA AND ELPHIDIIUM, COMMON FORAMINIFERA
ALONG THE TEXAS GULF COAST

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Abstract.—Species names for Ammonia and Elphidium have continually changed since these taxa were first described in Texas coastal environments. As a result, classification is problematic and the literature is inconsistent. The purpose of this paper is to evaluate the taxonomic status of species currently assigned to Ammonia and Elphidium. This task has been accomplished through extensive literature review and through comparison of specimens from this study with those in the Cushman Collection at the National Museum of Natural History. Most Elphidium found along the Texas coast are assignable to either Elphidium gunteri or E. excavatum, and the Ammonia present are assignable to Ammonia parkinsoniana and A. tepida. Present geographic, molecular and reproductive evidence shows that the species names A. parkinsoniana and A. tepida, not A. beccarii, should be used to describe these morphotypes of Ammonia wherever they occur, including the Gulf of Mexico, the east coast of North America, the Caribbean and the Pacific.

Since recent foraminifera on the Texas Gulf Coast were first described (Kornfeld 1931; Phleger & Parker 1951; Post 1951; Parker et al. 1953), species names for the most common estuarine taxa, Ammonia and Elphidium, have continually changed in the literature, making it difficult for subsequent workers to identify specimens. Specific names of these foraminifera have changed as it was recognized that many of the Gulf Coast morphotypes (shell types) are also found around the world (Miller et al. 1982; Buzas et al. 1985; Walton & Sloan 1990; Hayward et al. 1997; 1999), and that rather than being many separate species, a single species can have a variety of morphotypes (Schnitker 1974; Poag 1978; Miller et al. 1982; Walton & Sloan 1990; Stouff et al. 1999a).

The purpose of this paper is to assess the species names for the most commonly encountered morphotypes of Ammonia and Elphidium found in Texas coastal environments. The taxonomy proposed for Ammonia herein also affects the species name used for this morphotype on a worldwide basis. To determine current taxonomy, a survey of the literature was undertaken and specimens from Laguna Madre, Nueces Bay, the Arroyo Colorado, and Laguna Atascosa were compared with specimens in the Smithsonian National Museum of Natural History.
METHODS

Sediment cores, varying from 33 cm to 95 cm in length depending on bottom conditions, were taken at four sites along the south Texas coast:
Nueces Bay, southern Laguna Madre, the Arroyo Colorado, and Laguna Atascosa (Fig. 1). Since the spatial distribution of foraminifera is not uniform (Buzas 1968), four cores were taken at each locality in order to get an accurate representation of the taxonomic assemblages.

To evaluate living foraminifera present during sampling, the top 2 cm of the cores was stained with rose Bengal (Walton 1952; Murray & Bowser 2000), a protein-specific stain. Cores were sliced in 1 to 5 cm intervals (depending on other analyses performed), and 20 ml of sediment from selected intervals was washed through a 230 mesh (.062 mm) sieve. If foraminifera were not abundant, as in the Arroyo Colorado samples, they were concentrated for ease of counting using a sodium polytungstate flotation technique (Callahan 1987). From each locality, approximately 300 foraminifera were counted from the surface sediments of each core and from different depths in at least one core per site.

Specimens of *Elphidium gunteri*, *E. excavatum*, *Ammonia parkinsoniana* and *A. tepida* figured herein have been deposited in the Cushman Collection, National Museum of Natural History (USNM).

**RESULTS**

*Elphidium gunteri*, *E. excavatum*, *Ammonia parkinsoniana* and *A. tepida* (Figure 2) are the most common taxa at the sampling localities, together comprising from 60% to over 90% of the total assemblage in surface sediments and at depth. A range of shell types is exhibited within each of these species. Other taxa present at the sites are *Quinqueloculina seminula*, *Haynesina germanica* and *Ammotium salsum* (for a complete account of taxa, see Buzas-Stephens 2001).

Living *Ammonia* and *Elphidium* were found at all localities except for the Arroyo Colorado, where there were no living *Ammonia* and overall numbers (living plus dead) of *Ammonia* are low. The river has a history of poor water quality conditions (Bryan 1971) that may be responsible for the paucity of *Ammonia* (Buzas-Stephens 2001).

Interestingly, perfectly preserved Cretaceous through Eocene age foraminifera are present in the samples from southern Laguna Madre, the Arroyo Colorado, and Laguna Atascosa. Since much of the sediment in southern Laguna Madre is derived from offshore, many of these specimens are probably reworked at least a couple times from old Rio Grande delta distributary deposits (Rusnak 1960).
Figure 2. Most common species of *Ammonia* (except for *Ammonia beccarii*) and *Elphidium* present in Nueces Bay, Laguna Madre, the Arroyo Colorado and Laguna Atascosa (southern Texas). (2a) *Elphidium gunteri* Cole, scale = 200 μm, USNM 517707. (2b,c) *Elphidium excavatum* (Terquem), scale = 100 μm, (2b) USNM 517708; (2c) USNM 517709. (2d,e) *Ammonia beccarii* (Linne'), (2d) spiral view; scale = 907 μm; (2e) umbilical view, scale = 880 μm. Micrographs scanned from Walton & Sloan 1990 (Plate 3, Figs. 3a & 3b). This species is not present at the above localities, but is included here for comparison with *A. parkinsoniana* and *A. tepida*. (2f,g) *Ammonia parkinsoniana* (d'Orbigny), (2f) spiral view, scale = 200 μm, USNM 517710; (2g) umbilical view, scale = 100 μm, USNM 517711. (2h,i) *Ammonia tepida* (Cushman), (2h) spiral view, scale = 200 μm, USNM 517712; (2i) umbilical view, scale = 100 μm, USNM 517713.
SYSTEMATICS

Identification of the different species of *Ammonia* and *Elphidium* was accomplished through comparison of specimens from this study with those housed in the Cushman Collection, National Museum of Natural History (NMNH) in Washington, D.C. To ascertain identifications, hypotypes and specimens from Phleger & Parker (1951), Parker et al. (1953) and Poag (1981) were examined. Although many other authors have recorded species of *Ammonia* and *Elphidium* in Texas coastal environments (for a compilation, see Culver & Buzas 1981), most of these taxa are not illustrated and thus not available for comparison in future studies such as this.

Preliminary attempts to classify specimens from this work through illustrations and micrographs from Phleger & Parker (1951), Parker et al. (1953) and Poag (1981) were largely unsuccessful. Correct identifications were made only through direct comparison of individuals under the light microscope. Unless a worker is thoroughly familiar with an assemblage, identifications should be based on actual specimens, and not on figures from the literature.

The following taxonomy through the genus level is from Loeblich & Tappan (1987). Synonymies are presented for foraminiferal studies specific to the Texas Gulf Coast. Micrographs were taken with a Philips XL 30 ESEM.

Order FORAMINIFERIDA Eichwald
Suborder ROTALIINA Delage & Herouard
Superfamily ROTALIACEA Ehrenberg
   Family ELPHIDIIDAE Galloway
   Subfamily ELPHIDIINAE Galloway
   Genus *Elphidium* de Montfort
      *Elphidium gunteri* Cole
      Figure 2a

*Elphidium gunteri* Cole, 1931:34, pl. 4, figs. 9, 10.—Parker et al., 1953:8, pl. 3, figs. 18-19.—Parker, 1954:508, pl. 6, fig. 16.

*Elphidium gunteri* Cole var. *galvestonensis*.—Kornfeld (part), 1931:87-88, pl. 15, figs. 2a, b, 3a, b (not figs. 1a, b).—Post, 1951:172, pl. 1, fig. 14.

*Elphidium gunteri* Cole var. *galvestonense*—Phleger & Parker, 1951:10,
Cellanthus gunteri Cole, Wantland, 1969:109, pl. 3, fig. 5.


Material examined.—USNM 517707.

Distribution.—Elphidium gunteri comprises 8% of the total taxa in the surface sediments (0-2 cm) of Nueces Bay, 17% in Laguna Madre, 80% in the Arroyo Colorado and 10% in Laguna Atascosa.

Remarks.—As in coastal environments worldwide (Miller et al. 1982; Hayward 1997), the wide range of Elphidium shell types present along the Texas Gulf Coast provides a continual challenge to researchers attempting to assign them to species. One of the most common estuarine forms, which has straight sutures, prominent sutural bridges and umbilical bosses, and large, widely spaced pores has been consistently assigned to Elphidium gunteri Cole (Kornfeld 1931; Phleger & Parker 1951; Post 1951; Parker et al. 1953; Wantland 1969; Poag 1978; 1981) (Figure 2a). However, the above characteristics defining E. gunteri grade into other common morphotypes, including E. excavatum (Terquem) (Figures 2b & c). Since the characteristics of E. gunteri and E. excavatum can overlap (Buzas et al. 1985), it is sometimes difficult to assign a specimen to a species, even after counting thousands.

Elphidium excavatum (Terquem)

Figures 2b & c

Polystomella excavata Terquem, 1875:25, pl. 2, fig.2.

Elphidium translucens (Natland).—Post, 1951:173, pl. 1, fig. 17.—Parker et al, 1953:9, pl. 3, fig. 27.

Protelphidium delicatulum (Bermudez).—Wantland, 1969:110, pl. 3, fig. 7.


Material examined.—USNM 517708, 517709.
Distribution.—In the surface sediments *Elphidium excavatum* makes up 15% of the assemblage in Nueces Bay, 17% in Laguna Madre, 8% in the Arroyo Colorado and 11% in Laguna Atascosa.

Remarks.—Also ubiquitous to coastal environments worldwide (Miller et al. 1982; Buzas et al. 1985; Hayward 1997), *Elphidium excavatum* can generally be distinguished from *E. gunteri* by the presence of more numerous and smaller pores, lesser development of sutural bridges and fewer umbilical bosses. Because these features can vary widely within the species, *E. excavatum* has “probably been misidentified more than any other foraminiferal species” (Buzas et al. 1985). Until this study, the name *E. excavatum* has never been assigned to Texas coastal *Elphidium*, though Culver & Buzas (1981) provided synonymsies in their compilation of foraminiferal studies from the Gulf of Mexico. Instead, *E. excavatum* has mostly been referred to as *E. translucens* (Post 1951; Parker et al. 1953) or *E. delicatulum* (Parker et al. 1953; Wantland 1969), though it surely has had other synonyms as well. In the current project, *E. excavatum* and *E. gunteri* together comprise about 98% of all *Elphidium* found at each site, making these two species the most widespread and abundant species of *Elphidium* in southern Texas estuaries.

Although some authors have correlated the different shell types of *E. gunteri* and *E. excavatum* with environmental variables (Poag 1978; Miller et al. 1982), a similar correlation cannot be seen in this study. Perhaps future DNA and/or reproductive studies will help clarify the extent of genetic versus environmental control over the production of different *Elphidium* shell types.

Family ROTALIIDAE Ehrenberg  
Subfamily AMMONIIINAE Saidova  
Genus *Ammonia* Brunnich  
*Ammonia parkinsoniana* (d’Orbigny)  
Figures 2f & g

*Rosalina parkinsoniana* d’Orbigny, 1839:99, pl. 4, figs. 25-27.

*Rotalia beccarii* (Linne‘ var. *parkinsoniana* (d’Orbigny).—Kornfeld, 1931:90-91, pl. 13, figs. 1a, b, c.—Phleger & Parker, 1951:23, pl. 12, figs. 6a, b.

*Rotalia beccarii* (Linne’).—Post, 1951:176, pl. 1, fig. 20.
Rotalia beccarii (Linne') variant A.—Parker et al., 1953:13, pl. 4, figs.20-22.

Rotalia beccarii (Linne') variants.—Parker, 1954:531, pl. 10, figs. 1, 2, 5, 6.

Ammonia beccarii (Linne') variants.—Wantland, 1969:109, pl. 3, figs. 1a, b, c.

Ammoniaparkinsoniana (d'Orbigny) forma typica.—Poag, 1978:397, pl. 1, figs. 5-9, 13-16, 19-21.—Poag, 1981:38, pls. 45-46, figs. 1, 1a, 1b.

Material examined.—USNM 517710, 517711.

Distribution.—In surface sediments, Ammonia parkinsoniana comprises 63% of the total fauna in Nueces Bay, 21% in Laguna Madre, 4% in the Arroyo Colorado and 32% in Laguna Atascosa.

Remarks.—Among the different species of Ammonia found worldwide, there are three very common forms (Walton & Sloan 1990): (1) An ornamented shell morphotype that has distinct beading, fluting and/or furrowing along the sutures on one or both sides, and an umbilical plug (Figures 2d, e). This form was first described from the Mediterranean as A. beccarii (Linne' 1758); (2) An unornamented morphotype with an umbilical plug that lacks the above beading/fluting/furrowing along sutures (Figures 2f, g). This form was first described from the Caribbean as A. parkinsoniana (d’Orbigny 1839); and (3) A smaller, more lobate morphotype that has neither ornamentation nor an umbilical plug (Figures 2h, i), also first described from the Caribbean. This third morphotype is probably the A. catesbyana of d’Orbigny (1839). When updating d’Orbigny’s Cuban collection, Le Calvez (1977) designated a neotype for A. parkinsoniana, but apparently no identifiable specimens of A. catesbyana were available for the designation of a neotype for this species. In addition, d’Orbigny’s type figures are vague (Poag 1978), leaving the formal species name for the small lobate morphotype in question.

As well as having differences in overall appearance, the three morphotypes vary in their geographic ranges. The ornamented form occurs mainly in northern waters such as the Mediterranean, the northeastern Atlantic (no references are available south of 27N in the eastern Atlantic), and the western Atlantic near Cape Cod (Walton & Sloan
The other two morphotypes are found around the world (Walton & Sloan 1990), and are exclusive to southern oceans including the Pacific, Indian, and south Atlantic (Walton & Sloan 1990). They also occur in Texas estuaries and near shore in the Gulf of Mexico (Poag 1981; Walton & Sloan 1990).

In the early 1900s, Cushman (1926) began using the species name *A. beccarii* for all three forms, using variety names to distinguish them, and this terminology persisted. Thus the ornamented form was called *A. beccarii* var. *beccarii*, the one without ornamentation was *A. beccarii* var. *parkinsoniana*, and the lobate one without a plug was *A. beccarii* var. *tepida*. Many workers today refer to the smaller, lobate form as *A. tepida*, the varietal name first used by Cushman (1926). Neither "variety" nor "forma" names is governed by the International Code of Zoological Nomenclature (Ride et al. 1985).

In their classic studies documenting Texas Gulf Coast foraminifera, Kornfeld (1931), Phleger & Parker (1951) and Parker et al. (1953) also used the names *A. beccarii* var. *parkinsoniana* and *A. beccarii* var. *tepida* (or "Rotalia" *beccarii*, as the generic name became for awhile). Poag (1978) reinstated d'Orbigny's original name, *Ammonia parkinsoniana*, for the unornamented shell type, designating it as *A. parkinsoniana* forma *typica*. He called the lobate form *Ammonia parkinsoniana* forma *tepida*. Poag (1978) asserted that *A. parkinsoniana* was a different species than *A. beccarii* because the ornamented form does not occur in southern oceans (Poag 1978; Walton & Sloan 1990). Since Poag's re-introduction of the name *A. parkinsoniana*, both *A. parkinsoniana* (see Yuill 1991; Colburn & Baskin 1998) and *A. beccarii* (see Williams 1995) have been used to describe Texas Gulf Coast *Ammonia*.

More recent investigations into the DNA (Pawlowski et al. 1995; Holzmann & Pawlowski 1997; Holzmann 2000) and the life cycle (Goldstein & Moodley 1993; Stouff et al. 1999a) of *Ammonia* are helping to clarify the role genetics plays in producing these shell types. Through ribosomal DNA sequencing, Pawlowski et al. (1995) determined that the three morphotypes have distinct sequences indicating that they are separate species. Another molecular study (Holzmann & Pawlowski 1997) again shows that *A. tepida* can be distinguished genetically from another *Ammonia* morphotype. Holzmann (2000) further shows how different species of *Ammonia* found worldwide can be characterized according to morphology and DNA.
In the most current reproductive study, Stouff et al. (1999a) found that the different stages in the life cycle of *Ammonia tepida* have a characteristic shell forms. The asexual, diploid schizont stage typically has one or more umbilical plugs, while the sexual, haploid gamont stage lacks an umbilical plug. They did not observe the ornamented form as part of the life cycle of *A. tepida* or as a result of ontogeny. Likewise, ornamented offspring have not been produced from any cultures of *A. tepida* to date (Bradshaw 1957; Schnitker 1974; Goldstein & Moodley 1993; Stouff et al. 1999). However, Schnitker (1974) cultured two individuals of the ornamented form (*A. beccarii*), and reported "most of their offspring were similar to the *tepida* offspring".

To summarize, present geographic, reproductive, and molecular evidence show that the ornamented, unornamented and lobate morphotypes of *Ammonia* are separate species. Since the name *A. beccarii* was first assigned to the ornamented morphotype (Linne’ 1758), it should be reserved exclusively for this form. The name *A. parkinsoniana* (d’Orbigny 1839) is the valid name for the unornamented form, and apparently other authors agree with this conclusion (Jorissen 1988; Sen Gupta et al. 1996; Colburn & Baskin 1998; Hayward et al. 1999).

*Ammonia tepida* (Cushman)

Figures 2h & i

*Rotalia beccarii* (Linne’) var. *tepida* Cushman, 1926:79, pl. 1.—Kornfeld, 1931:91, pl. 13, figs. 3a, b, c.—Phleger & Parker, 1951:23, pl. 12, figs. 7a, b.—Post, 1951:176, pl. 1, figs. 21, 22.

*Rotalia beccarii* (Linne’) variants B, C.—Parker et al., 1953:13, pl. 4, figs. 25-30.

*Rotalia pauciloculata* (Phleger & Parker).—Phleger & Parker, 1951:23, pl. 12, figs. 8a, b, 9a, b.—Parker et al., 1953:13-14, pl. 4, figs. 31, 37.


*Ammonia beccarii* (Linne’) variants.—Wantland, 1969:109, pl. 3, figs. 2a, b, c, 3a, b, c.

*Ammonia parkinsoniana* (d’Orbigny) forma *tepida*.—Poag, 1978:397, pl. 1, figs. 1-4, 10-12, 17, 18.—Poag, 1981:37-38, pls. 45-46, figs. 2, 2a, b.
Table 1. Percent of *Ammonia parkinsoniana* versus *Ammonia tepida* as compared to salinity.

<table>
<thead>
<tr>
<th></th>
<th>Nueces Bay</th>
<th>Laguna Madre</th>
<th>Arroyo Colorado</th>
<th>Laguna Atascosa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salinity</td>
<td>27 ppt</td>
<td>26 ppt</td>
<td>14 ppt</td>
<td>6 ppt</td>
</tr>
<tr>
<td><em>A. parkinsoniana</em></td>
<td>96%</td>
<td>82%</td>
<td>45%</td>
<td>45%</td>
</tr>
<tr>
<td><em>A. tepida</em></td>
<td>4%</td>
<td>18%</td>
<td>55%</td>
<td>55%</td>
</tr>
</tbody>
</table>

**Material examined.**—USNM 517712, 517713.

**Distribution.**—*Ammonia tepida* comprises 2% of the assemblage in the surface sediments of Nueces Bay, 4% in Laguna Madre, 4% in the Arroyo Colorado and 39% in Laguna Atascosa. *Ammonia tepida* is more abundant than *A. parkinsoniana* at the sites with lower salinities (the Arroyo Colorado and Laguna Atascosa) (Table 1). Hayward et al. (1999) note a similar correlation with salinity, but Poag (1978) observed the opposite.

**Remarks.**—Although the taxonomy for the small, lobate morphotype will not be stabilized until a neotype is established, it is recommended that this form be assigned to *Ammonia tepida* since this name is already widely used (Pawlowski et al. 1995; Yanko et al. 1994; 1998; Geslin et al. 1998; Stouff et al. 1999a; 1999b).

**Conclusions**

The most common estuarine foraminifera found along the Texas Gulf Coast are *Elphidium gunteri*, *E. excavation*, *Ammonia parkinsoniana* and *A. tepida*. These species are also found worldwide. Since the defining characteristics of *E. gunteri* and *E. excavation* overlap, care must be exercised when assigning species names to these forms. *Elphidium excavation*, in particular, exhibits a wide range of shell morphotypes and thus can be quite challenging to identify. Current geographic, molecular and reproductive evidence shows that *A. parkinsoniana* and *A. tepida* have erroneously been called *A. beccarii* for most of the 20th century. The unornamented morphotype of *Ammonia* should be called *A. parkinsoniana* and the small, lobate form is *A. tepida*.

**Acknowledgments**

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LITERATURE CITED


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ANALYSIS OF HORSE (*EQUUS*) METAPODIALS FROM THE LATE PLEISTOCENE OF THE LOWER NUECES VALLEY, SOUTH TEXAS

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Abstract.—Ninety-eight relatively complete metapodials (29 metacarpals and 69 metatarsals) of *Equus* were recovered from late Pleistocene terrace and valley fill deposits along the Nueces River in western Nueces and San Patricio counties, Texas. Sixteen measurements were taken on each metapodial. Three species of *Equus* were determined to be present using discriminant functions and bivariate and multivariate plots of the data. *Equus* cf. *conversidens*, the most abundant species, is a small- to average-sized horse with normal length metapodials. It is similar to members of the *E. alaskae* group. The second species, represented by 24 metapodials, is assigned to *E. cf. scotti*. These are larger horses with robust limbs that resemble members of the *E. scotti* and *E. laurentius* groups. The third, represented by six specimens, is a stilt-legged horse of the *E. francisci* group.

The Wright Material Inc., sand and gravel pits along the Nueces River in western Nueces and San Patricio counties, Texas have produced a diverse assemblage of late Pleistocene fossils. Twenty-six species of mammals have been identified from here (Baskin 2000). Equids are among the most common fossils recovered. Living *Equus* includes horses, asses and zebras. Identification of fossil *Equus* to species from isolated teeth and bones is difficult at best (Winans 1989; Dalquest & Schultz 1992). Additionally, although most of the approximately 60 North American species that have been named are junior synonyms or invalid, the taxonomy of *Equus* itself is far from agreed on. Dalquest & Schultz (1992) identified seven or eight species of *Equus* from the Pleistocene (Irvingtonian and Rancholabrean) of northwestern Texas alone. Azzaroli (1998) recognized up to ten Pleistocene North American species. Winans (1989) recognized five species groups of North American *Equus*, of which no more than four groups were extant at a given time. Winans (1989) considered the possibility that each group represented a single species and that therefore only four species of *Equus* were present in North America during the Pleistocene.

The purpose of this paper is to determine how many species of *Equus* were present in the late Pleistocene Nueces River Valley deposits of south Texas and identify them. Voucher specimens are deposited with the holdings of the Texas Memorial Museum (TMM) of the University of Texas, Austin.
Geologic Setting

Four alluvial terrace units and three younger valley fill units are recognized from late Pleistocene and Holocene sediments in the lower Nueces River Valley, Nueces and San Patricio counties, west of Corpus Christi, Texas, between Odem and Mathis, where the Nueces River is entrenched in the late Pleistocene Beaumont Formation (Cornish & Baskin 1995). The valley fill units are included in the Cayamon Creek Alloformation. Most of the metapodials described in this paper come from channel fill and point bar sands and gravels of the Cayamon Creek allomember 1 at the Wright Materials, Inc. quarries (TMM localities 43059 and 43064), approximately 4 km north of Bluntzer, Nueces County, Texas. A log buried in this unit has been carbon dated at 13,230 ± 110 YBP (Baskin 1991). Seven metatarsals were recovered across the river in the Angelita Terrace, San Patricio County (TMM locality 18594). These late Quaternary terraces and valley fill deposits have produced a mixed assemblage of early Pliocene and Pleistocene fossil vertebrates. The Pliocene horses are reworked from older updip deposits, presumably of the upper Goliad Formation (Baskin 1991).

Whether the Pleistocene vertebrates are all contemporaneous with the latest Pleistocene alluvium or are to some degree reworked cannot be easily determined. There is a wide variation in the nature of the preservation. Some of the bones and teeth are darkly stained and appear to be partly mineralized. Other specimens are quite fresh in appearance. The fossils consist mainly of isolated teeth and durable postcranial elements such as astragali, phalanges and metapodials that indicate that transportation and sorting of specimens has occurred (Hanson 1980). Some of the specimens are waterworn, but most are not. The fact that there are more than twice as many complete metatarsals as metacarpals is further evidence of hydrodynamic sorting. The presence of jaws of Equus, Bison, Tapirus and Camelops and a mammoth skull and associated partial skeleton suggests that some, if not most, of the Pleistocene specimens were not transported very far. Bison in the fauna is also indicative of a Rancholabrean (late Pleistocene) age. The presence of both Bison latifrons and B. antiquus may indicate some degree of mixing for the Rancholabrean fauna, because B. latifrons is sometimes considered an early Rancholabrean species (Guthrie 1970). However, B. latifrons may have survived into the late Rancholabrean (Pinsof 1991; Wyckoff & Dalquest 1997).
METHODS AND MATERIALS

Metapodials are usually the most useful skeletal element available for identifying fossil Equus (Winans 1989). Skulls are rarely preserved and isolated teeth are highly variable. Ninety-eight complete metapodials (29 metacarpals and 69 metatarsals) were analyzed. Sixteen measurements (Eisenmann 1979; Winans 1989) were taken on each (Tables 1, 2). All measurements are in mm. Winans (1989: table 14.1) developed discriminant functions based on eight of these measurements to assign specimens to one of her five species groups: the E. simplicidens (early Blancan), E. scotti (late Blancan to early Rancholabrean), E. laurentius (Rancholabrean), E. francisci (Irvingtonian to Rancholabrean), and E. alaskae (Irvingtonian to Rancholabrean) groups. The Nueces River metapodials were initially assigned to one of the five species groups using these discriminant functions. Because reliability of these discriminant functions to correctly assign specimens to species varied from 61-91% (Winans 1989), the measurements were analyzed graphically using bivariate and multivariate plots (Figs. 1, 2) of the data to look for groupings of specimens and to emend species assignments. For the principal components analyses (Fig. 2), measurements (Tables 1, 2) used are 1, 4, 5, 10, 12, 14 and 15 for the metacarpals, and 1, 4, 5, 6B, 7, 10, 11, and 15 for the metatarsals (Fig. 2). This was done to compare the Nueces River results with the average values Winans (1989) used to determine her discriminant functions.


RESULTS

The most common equid species from the Nueces River gravel pits is represented by 13 metacarpals and 42 metatarsals. These form relatively distinct clusters (Figs. 1, 2) centered near average values for the E. alaskae group of Winans (1989: table 14.2). They are assigned to Equus cf. conversidens, a small- to medium-sized horse with normally proportioned (i.e., stout-legged) metapodials. Winans (1989) assigned the small, stout-legged horses of Rancholabrean age to the Equus alaskae (originally E. niobrarensis alaskae) group. Azzaroli (1998) synonymized E. niobrarensis alaskae and E. laurentius with E. ferus.
Table 1. Univariate statistics on metacarpal III's of *Equus* from the Nueces River Valley. Measurements are 1, greatest length [1, 1]; 2, lateral length [2, - ]; 3, mid-shaft width [3, 6]; 4, mid-shaft anteroposterior breadth [4, 7]; 5, proximal articular width [5, 2]; 6, proximal articular breadth [6, 3]; 7, width of magnum facet [7, 5]; 8, width of anterior unciform facet [8, - ]; 8', width of posterior unciform facet [8', - ]; 9, width of trapezoid facet [9, - ]; 10, distal supra-articular width [10, 8]; 11, distal articular width [11, 9]; 12, anteroposterior breadth of median ridge of trochlea [12, 11]; 13, least breadth of medial distal condyle [13, - ]; 14, greatest breadth of medial distal condyle [14, 10]; 15, width plantar process [-, 4]. Numbers in brackets refer to the corresponding measurements in Eisenman (1986, fig. 39) and Winans (1989, fig. 14.5), respectively. A "*" indicates that measurement was not used by the respective author.

<table>
<thead>
<tr>
<th></th>
<th>Equus cf. conversids</th>
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<th>Equus cf. scotti</th>
<th></th>
<th>Equus cf. francisci</th>
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<td>n</td>
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<td>OR</td>
<td>cv</td>
<td>n</td>
<td>X ± SD</td>
<td>OR</td>
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<td>224-252</td>
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<tr>
<td>2</td>
<td>13 215.5 ± 5.076</td>
<td>208-226</td>
<td>2.4</td>
<td>11 229.6 ± 8.65</td>
<td>217-245</td>
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<td>13 31.91 ± 1.879</td>
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<td>4 7.25 ± 1.613</td>
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<td>13 40.63 ± 4.377</td>
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<td>7.9</td>
<td>11 33.81 ± 1.822</td>
<td>30.8-36.2</td>
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Table 2. Univariate statistics on metatarsal III's of *Equus* from the Nueces River Valley. Measurements are 1, greatest length [1, 1]; 2, lateral length [2, -]; 3, mid-shaft width [3, 6]; 4, mid-shaft anteroposterior breadth [4, 7]; 5, proximal articular width [5, 2]; 6a, medial proximal articular breadth [6, -]; 6b, lateral proximal breadth [3, -]; 7, width of ectotunceiform facet [7, 5]; 8, breadth of cuboid facet [8, -]; 9, breadth of mesotunceiform facet [9, -]; 10, distal supra-articular width [10, 8]; 11, distal articular width [11, 9]; 12, anteroposterior breadth of median ridge of trochlea [12, 11]; 13, least breadth of medial distal condyle [13, -]; 14, greatest breadth of medial distal condyle [14, 10]; 15, width plantar process [-, 4]. Numbers in brackets refer to the corresponding measurements in Eisenman (1986, fig. 39) and Winans (1989, fig.14.5), respectively. A "-" indicates that measurement was not used by the respective author.

<table>
<thead>
<tr>
<th></th>
<th><em>Equus cf. conversidens</em></th>
<th></th>
<th><em>Equus cf. scotti</em></th>
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<th><em>Equus cf. francisci</em></th>
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<td>cv</td>
<td>n</td>
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<td>6B</td>
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<tr>
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<td>41</td>
<td>28.39 ± 2.348</td>
<td>22.3-34.2</td>
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Figure 1. Scatterplots of greatest length versus distal articular width for medial metacarpals and metatarsals of Equus. Circles are specimens from the Nueces River Valley assigned to E. cf. conversidens, to E. cf. scotti; inverted triangles, to E. cf. francisci; and stars, to E. sp. The letters P, S, L, F and A refer to the average values for these measurement for the E. simplicidens, E. scotti, E. laurentius, E. francisci and E. alaskae groups (Winans 1989), respectively.

(=E. caballus - the extant domestic horse). He retained E. conversidens for the horse from San Josecito Cave and the smaller horse from Slaton (Dalquest & Hughes 1965). The dimensions of these metapodials (Tables 1, 2) are similar to those of Equus species A from the Irvingtonian Leisey Shell Pit of Florida. Hulbert (1995) noted that this taxon was intermediate in tooth row length between E. conversidens and E. scotti. However, metatarsals from Slaton assigned to E. conversidens are similar in length and distal width to the Leisey and Nueces River taxon. Length and distal width of metapodials of E. conversidens from San Josecito Cave are also within this range (Lundelius 1984).

These metapodials have somewhat higher coefficients of variation (Tables 1, 2), even for length, when compared to samples that are
Figure 2. Principal components analysis using a covariance matrix on six measurements taken on medial metacarpals and metatarsals. See Fig. 1 for an explanation of the symbols and Tables 1 and 2 for measurements used. Principal component one accounted for 72% and 82% of the variance, and principal component 2, 24% and 14% for the metacarpals and metatarsals respectively.

probably not as temporally mixed, such as Rancho La Brea (Willoughby 1948) or Leisey (Hulbert 1997). This may indicate that more than one species is represented or time averaging within this species has occurred. Removing the six smallest metatarsals results in CV’s that are comparable to the Rancho La Brea or Leisey samples. Although, these six are within the size range given by Winans for the E. alaskae (or even E. scotti) group, they could represent early Pliocene Dinohippus or a smaller species of Equus (e.g., E. tau, although Dalquest [1979] assigned relatively elongate metatarsals to that species). Two of these specimens are very worn distally, three display average wear, and one has no evidence of transport. Mooser & Dalquest (1975) attributed metatarsals and dentitions of the smallest horses from Cedazo to E. conversidens. These are similar in size to these six smallest Nueces River specimens. Somewhat larger, but similarly proportioned metatarsals, were assigned to E. excelsus (Mooser & Dalquest 1975). Rodriguez Avalos (1999) referred all horses from Cedazo to a single species. Dalquest (1979) referred metatarsals 240-265 mm in length to E. conversidens, which would also include E. excelsus from Cedazo. Howe (1970) reported high CV values for E. simplicidens from Broadwater, comparable to the Nueces River sample, and concluded that because measurements were normally distributed, only a single species was present. Likewise, the smallest Nueces metatarsals are retained in E. cf. conversidens.
Equus cf. scotti is represented by 11 metacarpals and 24 metatarsals that are for the most part intermediate in size between the mean measurements determined by Winans (1989) for her E. scotti and E. laurentius groups. These are large horses with normally proportioned to robust limbs. Measurements (Tables 1, 2) are similar to those for E. occidentalis from Rancho La Brea (Willoughby 1948). The discriminant functions of Winans (1989) assigned the smaller of these individuals to the E. scotti group, the larger to the E. laurentius group. Four of the five metacarpals assigned to the E. scotti group are relatively short and stout. Winans (1989) used the E. scotti group for late Blancan to early Rancholabrean large, stout-legged horses and included E. hatcheri and E. niobrarensis in this group. Winans used the E. laurentius group for later Rancholabrean large horses which are similar to E. scotti. Equus laurentius is probably based on a recent specimen (Winans 1989; Azzaroli 1998) and is therefore an invalid name. Winans (1989) referred E. occidentalis to the E. laurentius group. Scott (1998) stated that E. scotti was replaced by E. occidentalis in the late Pleistocene of California.

The most important previous collections of Rancholabrean Equus from South Texas are from Ingleside (Lundelius 1972), Berclair terraces (Quinn 1957), and Cueva Quebrada (Lundelius 1984). The Ingleside sample, which does not include any metapodials, was originally referred to three species: most of the specimens to E. complicatus, a few larger specimens to E. pacificus and a few smaller to E. fraternus. Winans (1989) referred the entire sample to the E. scotti group. Two species were described from Cueva Quebrada: a stouter E. cf. scotti and a slenderer E. francisci. Winans (1989) referred the stout-limbed species to the E. laurentius group; the stilt-limbed is not discussed, but belongs to the E. francisci group. The stout-legged metapodials are similar to those from the Nueces River Valley. Azzaroli (1998) referred the large stout-limbed horses from the late Pleistocene of South Texas to E. excelsus, which he considered a senior synonym of E. scotti. He differentiated E. excelsus from E. occidentalis on the basis of dentition, but suggested the two were closely related. Dalquest & Schultz (1992) stated that E. excelsus was a medium-sized horse and that the larger caballine horses of the late Pleistocene may have been E. scotti.

The third species, represented by six specimens, is a stilt-legged ass of the E. francisci group. The metapodials are similar in size to specimens assigned to E. francisci (e.g., Lundelius & Stevens 1970;
Lundelius 1984). The type of *E. francisci* is from the Lissie Formation, Wharton County, Texas (Lundelius & Stevens 1970). Dalquest and Schultz (1992) recognized three or four species of stilt-legged horses, including *E. pseudaltidens*. *Equus pseudaltidens* (Hulbert 1995) was described from the late Pleistocene Berclair terrace, Bee County, Texas as *Onager altidens* Quinn (1957). The reported metatarsal length is 283 mm, similar in size to specimens referred to *E. francisci*. Based on dental characteristics, Hulbert considered *E. pseudaltidens* to be distinct from *E. francisci*.

**ACKNOWLEDGMENTS**

Dedicated to the memory of W. W. Dalquest. I am very grateful to the management of Wright Materials, Inc., particularly M. Truesdale and L. and R. Wright, for permission to collect on their property. A. Mosqueda was funded by the Ronald E. McNair Scholars Program. Without the dedication of R. Thomas of TAMUK, who collected most of the metapodials, this paper would not have been possible. The North American Mammalian Paleofaunal Database (Alroy 2000) was consulted for background information. Constructive comments were offered by Richard Hulbert and Ernest Lundelius. This study was funded in part by Texas A&M University-Kingsville.

**LITERATURE CITED**


JAB at: J-Baskin@tamuk.edu
SILICA-SCALED CHRYSOPHYTES AND SYNUROPHYTES FROM EAST TEXAS

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Mt. Pleasant, Michigan 48859
Department of Biological Sciences, Loyola University
6363 St. Charles St., New Orleans, Louisiana 70118 and
Department of Biology, Stephen F. Austin State University
Nacogdoches, Texas 75962

Abstract.—A total of 27 scale-bearing species of the algal classes Chrysophyceae and Synurophyceae, referred to herein as scaled chrysophytes, were recorded in 35 water bodies from 11 eastern Texas counties using transmission electron microscopy. These were distributed between the Chrysophyceae (one Chrysosphaerella sp., one Paraphysomonas sp. and two Spiniferomonas sp.) and Synurophyceae (14 Mallomonas sp. and nine Synura sp.). The number of taxa per collection varied from zero to six. Twenty-three taxa are new records for Texas. Mallomonas multisetigera is reported for the first time from North America. Scales of the colorless free-living flagellate Gyromitus disomatus, an organism of uncertain taxonomic affinity, were also observed.

Surveys of the freshwater algal flora of Texas were initiated through a series of investigations by H. C. Bold and his students (Deason & Bold 1960; Chantanachat & Bold 1962; Bischoff & Bold 1963; Brown & Bold 1964; Cox & Bold 1966; Smith & Bold 1966; Groover & Bold 1969; Archibold & Bold 1970; Baker & Bold 1970. Other studies have included Texas collections, but were not directed specifically on the Texas flora (Flint 1955; Nicholls 1964; Hoffman 1967; Ott 1976; Carty 1989; Carty & Cox 1985; 1986; Sheath et al. 1993a; 1993b; Swamikannu & Hoagland 1990; Vis & Sheath 1996). All of these reports are based on light microscopy.

Silica-scaled chrysophytes are taxonomically placed in the division Chrysophyta, classes Chrysophyceae and Synurophyceae, based on ultrastructural and biochemical characteristics (Andersen 1987). The majority of chrysophyte genera lack a covering of siliceous scales and exhibit a great plasticity in regard to both morphology and nutrition (Hoek et al. 1995). Most of the common chrysophytes are flagellated, occurring as single cells or are colonial.

The first electron micrographs of silica-scaled chrysophytes from Texas are in the unpublished report of Marquis (1977) based on col-
lections made in the Edwards Plateau located at the southern most end of the High Plains province (Cole 1966). The chrysophyte flora of neighboring Louisiana (Wee et al. 1993), the nearby state of Arizona (Gretz et al. 1979; 1983; 1985), and the country of Mexico (Kristiansen & Tong 1995) also have been studied previously using electron microscopy. Adjacent states, such as New Mexico and Oklahoma remain to be investigated.

In this study, the silica-scaled algal flora from 11 counties representing 35 eastern Texas locations in the western Coastal Plain physiographic province (Cole 1966) were examined using transmission electron microscopy (TEM).

**Materials and Methods**

Phytoplankton samples were collected with a plankton net (10 μm mesh size) in mid-March of 1996 from 35 ponds and lakes in 11 Texas counties (Table 1). Samples were fixed in acid Lugol’s (Wee 1983). For TEM, subsamples were placed on Formvar-coated, carbon-stabilized grids, air dried and examined with a Philips 300 transmission electron microscope. All identifications were based on TEM. Percentages were based on the number of samples in which a taxon was observed divided by the total number of samples. Physical/chemical parameters taken in the field were surface water temperature, pH (Markson model 85), and specific conductance (Oakton WD-60). In an attempt to identify coordinated variation between physical/chemical parameters and species composition of the samples, the data were subject to multivariate analyses, including Detrended Correspondence Analysis (DCA, Hill 1979) and Canonical Correspondence Analysis, (CCA, ter Braak 1992). Species occurring in only one sample were eliminated prior to analysis, resulting in a data set of 17 samples and 31 taxa. All micrographs documenting this study are on deposit in the herbarium of Central Michigan University.

**Results and Discussion**

The taxa identified, and the collection sites for each taxon are listed in Table 2. Twenty-seven silica-scaled synurophycean and chrysophycean taxa from five genera, *Mallomonas* (14 taxa), *Synura* (10 taxa), *Spiniferomonas* (two taxa), *Paraphysomonas* and *Chrysosphaerella* (one taxon each) were observed from the 35 samples. All scale morphologies were similar to those in the published literature.
Table 1. Eastern Texas plankton collection sites containing silica-scaled chrysophytes and synurophytes, plus physical/chemical data and number of taxa observed for each site, 17 March to 20 March, 1996.

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<th>Sample No.</th>
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<th>Temperature °C</th>
<th>Conductivity μS/M</th>
<th>#taxa obs.</th>
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<tr>
<td>2</td>
<td>William Roberts Pond</td>
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</tr>
<tr>
<td></td>
<td>At Shelbyville - spring fed</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Center City Reservoir</td>
<td>7.1</td>
<td>23.8</td>
<td>117.2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>½ mile east of US 96, 3 miles south of Center</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Pinkston Reservoir</td>
<td>7.7</td>
<td>22.8</td>
<td>105.8</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Near Aiken, southwest corner of county</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Nacogdoches County - 17 March, 1996</td>
<td>6.8</td>
<td>21.9</td>
<td>150.0</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Jasper County - 17 March, 1996</td>
<td>6.5</td>
<td>22.3</td>
<td>147.0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>BA Steinhagen Lake</td>
<td>Martin Dies Jr. State Park, south of US 190</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Nacogdoches County - 17 March, 1996</td>
<td>6.5</td>
<td>13.8</td>
<td>103.9</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Rusk County - 17 March, 1996</td>
<td>6.7</td>
<td>16.5</td>
<td>279.0</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>Lake Striker</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Craig’s Pond</td>
<td>6.7</td>
<td>18.3</td>
<td>92.2</td>
<td>4</td>
</tr>
<tr>
<td>11</td>
<td>Willow Lake</td>
<td>In Henderson</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Martin Lake</td>
<td>Martin Lake State Park</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Panola County - 17 March, 1996</td>
<td>6.7</td>
<td>16.9</td>
<td>190.3</td>
<td>5</td>
</tr>
<tr>
<td>14</td>
<td>Rusk County - 19 March, 1996</td>
<td>6.6</td>
<td>14.8</td>
<td>89.8</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Doc Young Pond</td>
<td>Impoundment, about 2+ miles west of Tabem on north side of Texas Hwy 43 (1¼ miles east of Road 1716)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Pond</td>
<td>Northeast side of Road 1716, 1½ miles northwest of Texas Hwy 43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Lake Cherokee</td>
<td>Small arm crossing Farm Road 1716</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Long Glade Lake</td>
<td>Boat launch, west side of Road 2127, 2 miles south of Lake Cherokee</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>J.W. Walters Pond</td>
<td>East side of Road 2127, 2 miles north of Road 1727</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Lake Forest Park</td>
<td>In west Hendersonville, south side of Texas Hwy 64</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Smith County - 19 March, 1996</td>
<td>6.7</td>
<td>18.3</td>
<td>101.3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Pleasure Acres Lake</td>
<td>Lake at subdivision, north of Texas 64, northwest of New Chapel Hill</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 1 cont.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Location</th>
<th>pH</th>
<th>Temperature °C</th>
<th>Conductivity μS/M</th>
<th>#taxa obs.</th>
<th>Henderson County - 19 March, 1996</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Pond</td>
<td>7.8</td>
<td>16.6</td>
<td>128.7</td>
<td>1</td>
<td>West of Pleasure Acres Lake entry road</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>Lake Tyler</td>
<td>6.7</td>
<td>18.2</td>
<td>95.3</td>
<td>4</td>
<td>Near southeast side of Farm Road 848</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Henderson County - 19 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>Lake Palestine</td>
<td>6.5</td>
<td>15.0</td>
<td>176.9</td>
<td>0</td>
<td>Near southeast side of Farm Road 155</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cherokee County - 19 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Lake Jacksonville</td>
<td>6.5</td>
<td>15.9</td>
<td>84.7</td>
<td>2</td>
<td>Northwest part just east of Farm Road 747</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nacogdoches County - 19 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Whisper Oaks Pond</td>
<td>8.3</td>
<td>16.5</td>
<td>88.1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harrison County - 20 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>Lake</td>
<td>7.0</td>
<td>13.5</td>
<td>396.0</td>
<td>2</td>
<td>On south side of access road that parallels I 20, just east of US 259, exit at Lakeport</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Privately owned lake</td>
<td>6.8</td>
<td>13.8</td>
<td>72.1</td>
<td>3</td>
<td>Between I 20 and US 80 east of Longview, west of Ring Road [281] just south of County 3417</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>Highway Lake</td>
<td>6.9</td>
<td>17.4</td>
<td>113.1</td>
<td>3</td>
<td>In small subdivision, east of Longview, south side of Highway 80, accessed via County 3427, composite sample from both sides of dam between 2 biggest ponds</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Big Rock Lake</td>
<td>6.9</td>
<td>13.5</td>
<td>47.4</td>
<td>4</td>
<td>East of Farm Road 450, east of Longview, between US 80 and Farm Road 449</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marion County - 20 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Lake of the Pines</td>
<td>6.5</td>
<td>14.2</td>
<td>134.1</td>
<td>1</td>
<td>At Island View boat ramp, south side of lake</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upshur County - 20 March, 1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Barton Lake</td>
<td>6.5</td>
<td>16.4</td>
<td>97.7</td>
<td>2</td>
<td>East of Gilmer on south side of Texas 154 bridge</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>Beaver Pond</td>
<td>6.8</td>
<td>16.1</td>
<td>136.0</td>
<td>1</td>
<td>South of Gilmore, north side Bluebird Road between US 271 and Texas 300</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>South Twin Lake</td>
<td>6.4</td>
<td>15.7</td>
<td>77.1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>North Twin Lake</td>
<td>6.6</td>
<td>13.6</td>
<td>88.1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>Spencer's Pond</td>
<td>7.5</td>
<td>12.0</td>
<td>619.0</td>
<td>2</td>
<td>West side of US 217, south of Gilmore, 1 mile north of Eagle and Evergreen Roads</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Big Sandy Lake</td>
<td>6.6</td>
<td>13.9</td>
<td>93.3</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>
Table 2. Species of silica-scaled chrysophytes and synurophytes from eastern Texas. See Table 1 for description of locations. Taxa indicated with an asterisk (*) are new reports for Texas; double asterisks (**) are new for North America.

<table>
<thead>
<tr>
<th>Taxon</th>
<th>Collection Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chrysophyceae</strong></td>
<td></td>
</tr>
<tr>
<td>Chrysosphaerella</td>
<td></td>
</tr>
<tr>
<td><em>C. coronacircumpina</em> Wujek &amp; Kristiansen</td>
<td>11</td>
</tr>
<tr>
<td><strong>Paraphysomonas</strong></td>
<td></td>
</tr>
<tr>
<td><em>P. vestita</em> (Stokes) de Saedeleer</td>
<td>6, 8, 11, 34</td>
</tr>
<tr>
<td><strong>Spiniferomonas</strong></td>
<td></td>
</tr>
<tr>
<td><em>S. crucigera</em> Takahashi</td>
<td>15</td>
</tr>
<tr>
<td><em>S. trioralis</em> Takahashi</td>
<td>1, 5, 11, 12, 15, 18, 21, 23, 34</td>
</tr>
<tr>
<td><strong>Synurophyceae</strong></td>
<td></td>
</tr>
<tr>
<td>Mallomonas</td>
<td></td>
</tr>
<tr>
<td><em>M. akrokomos</em> Ruttner in Pascher</td>
<td>7, 15</td>
</tr>
<tr>
<td><em>M. annulata</em> (Bradley) Harris</td>
<td>31</td>
</tr>
<tr>
<td><em>M. caudata</em> Ivanov em. Krieger</td>
<td>7, 26, 27, 28, 30, 32</td>
</tr>
<tr>
<td><em>M. crassisquama</em> (Asmund) Fott</td>
<td>7, 12, 23, 32</td>
</tr>
<tr>
<td><em>M. doignonii</em> Bourrely em. Nicholls</td>
<td>16</td>
</tr>
<tr>
<td><em>M. elongata</em> Reverdin</td>
<td>10</td>
</tr>
<tr>
<td><em>M. hamata</em> Asmund</td>
<td>2, 17, 31, 32</td>
</tr>
<tr>
<td><em>M. heterospina</em> Lund</td>
<td>12</td>
</tr>
<tr>
<td><em>M. mangofera</em> Harris &amp; Bradley</td>
<td>25, 32</td>
</tr>
<tr>
<td><em>M. papillosa</em> Harris &amp; Bradley</td>
<td>18</td>
</tr>
<tr>
<td><strong>M. multisetigera</strong> Dürrschmidt</td>
<td>9</td>
</tr>
<tr>
<td><em>M. portae-ferreae</em> Péterfi &amp; Asmund</td>
<td>4, 12</td>
</tr>
<tr>
<td><em>M. transsylvanica</em> Péterfi &amp; Momeu</td>
<td>3, 35</td>
</tr>
<tr>
<td><em>M. tonsurata</em> Teiling</td>
<td>21, 25, 26, 28, 29, 32, 33</td>
</tr>
<tr>
<td>Synura</td>
<td></td>
</tr>
<tr>
<td><em>S. australiensis</em> Playfair em. Croome &amp; Tyler</td>
<td>13, 14, 27, 28, 32</td>
</tr>
<tr>
<td><em>S. curtispina</em> (Petersen &amp; Hansen) Asmund</td>
<td>24, 32</td>
</tr>
<tr>
<td><em>S. echinulata</em> Korshikov</td>
<td>1, 2, 13, 19, 20, 21, 35</td>
</tr>
<tr>
<td><em>S. mollisquina</em> Korshikov</td>
<td>13</td>
</tr>
<tr>
<td><em>S. petersenii f. petersenii</em> Korshikov</td>
<td>1, 3, 7, 12, 13, 14, 29</td>
</tr>
<tr>
<td><em>S. petersenii f. glabra</em> (Korshikov) Siver</td>
<td>1, 5, 15</td>
</tr>
<tr>
<td><em>S. sphagnicola</em> Korshikov</td>
<td>13</td>
</tr>
<tr>
<td><em>S. spinosa f. spinosa</em> Korshikov</td>
<td>15, 21, 29</td>
</tr>
<tr>
<td><em>S. uvella</em> Stein em. Korshikov</td>
<td>1, 13, 14, 15, 17, 26, 27, 28, 29, 30, 32, 33</td>
</tr>
<tr>
<td><strong>Classis insertae</strong></td>
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</tr>
<tr>
<td><em>Gyromitus disomatus</em> Skuja</td>
<td>21</td>
</tr>
</tbody>
</table>

The number of scale-bearing chrysophyte taxa observed per sample varied from zero to six (Table 1). Species richness was greatest at three sites, Doc Young Pond, Lake Cherokee and South Twin Lake, where some of the lowest water temperatures, ranging from 14.8-15.7°C, were observed (Table 1). The most frequent Mallomonas species were *M. tonsurata* (20%), *M. caudata* (17%) and *M. crassisquama* and *M. hamata* (11% each). Common species from other genera were Synura uvella (34%), *S. echinulata* and *S. petersenii f. petersenii* (both 20%),
S. australiensis (14%) and Spiniferomonas trioralis (23%). Species observed from only one collection site included Mallomonas annulata, M. doignonii, M. elongata, M. heterospina, M. mangofera, M. papillosa, Synura curtispina, S. mollispina, Spiniferomonas crucigera and Chrysosphaerella coronacircumspina. Additionally, Mallomonas multisetigera is newly reported for North America (Fig. 1a).

Scaled chrysophytes were observed in every collection except Lake Palestine (sample 22). The reason(s) for this is unknown.

In the scanning electron microscope examination of samples from the Edward's plateau through central and northeastern Texas, Marquis (1977) observed nine Mallomonas taxa. This current study observed four of Marquis' (1977) taxa: Mallomonas caudata, M. doignonii, M. mangofera (as M. texensis) and M. transsylvanica. Mallomonas asmundiae, M. corymbosa, M. lychenensis, M. pseudocoronata and M. teilingii var. papillosa nomen nudum were not observed during this current study.

Scales of Gyromitus disomatus Skuja (Fig. 1b), a colorless free-living flagellate of unknown taxonomic affinity, were observed in the Lake Tyler sample. This organism has no obvious affinities with any taxonomic group (Swale & Belcher 1974). Nicholls (1979), using X-ray emission spectra, has shown that the scales are composed of silica, but not calcified, and hence do not represent coccoliths.

Specific conductance across all collections ranged from 47.4 to 619.0 μS/M. For the ten most frequently observed species, Synura echinulata and Mallomonas crassisquama had the narrowest ranges, 89.8 to 128.7 and 49.4 to 109.3 μS/M, respectively. The largest ranges were observed in Synura uvella (47.4 - 371.0 μS/M) and Spiniferomonas trioralis (84.7 - 371.0 μS/M). These are very close to the ranges reported by Wujek & Menapace (1998). As Siver (1993) reported, until more conductivity studies are published, it is unknown "at this time whether individual taxa are responding to specific anions and cations or some combination thereof."

The range in water temperatures (12.0 to 24.3 °C) and the time of year may indicate that the collections contained elements of both late spring and summer floras. Species observed, such as Mallomonas akrokomos and M. transsylvanica, have been observed under the ice in more northern regions (Cronberg & Kristiansen 1980; Siver 1991).
Taxa such as *M. crassisquama*, *M. tonsurata* and *Synura curtispina*, are more commonly observed during the summer (Siver 1991), supporting the hypothesis that collections made during this current study contain some taxa common in summer and others more common in the spring or winter. With additional sampling, especially in colder waters, given that collections were taken during mid March when the surface water had begun to warm (Table 1), it is suspected that additional warm water species and cooler water taxa known to occur in the southeastern U.S. will be found to occur in Texas.

The pH of the collections ranged from 6.4 to 8.3. Many of the species observed in localities with low pH values, including *Mallomonas hamata*, *M. transsylvanica*, *Synura echinulata* and *S. sphagnicola*, have been reported previously as common in acidic habitats (Siver 1988; 1989; 1991; Wujek & Menapace 1998). Observations made during this study clearly support these earlier findings.

*Synura petersenii* f. *petersenii* occurred in the largest pH range, 6.5 to 7.1, for the most prevalent taxa followed by *S. australiensis*, *S. uvella* and *Mallomonas caudata*, 6.4 to 6.9 and then *M. tonsurata* with 6.6 to 7.0. Both *Mallomonas crassisquama* and *Synura echinulata* had the narrowest ranges (Table 1). The data for all nine species are within the values reported in the literature.

Multivariate analysis did not demonstrate clear relationships between the measured physical/chemical parameters and the scaled chrysophyte
and synurophyte species composition of the samples. The first, second and third axes of a DCA ordination of the samples, which was based on the presence of scaled chrysophyte and synurophyte taxa, were not significantly correlated with any of the measured parameters. Likewise, a Canonical Correspondence Analysis showed low species-environment correlations. A Monte Carlo test of the CCA model using 100 random iterations failed to reject the hypothesis that no relationship existed between the species-samples matrix and the matrix of physical/chemical parameters.

Several explanations exist for the apparent lack of correspondence between the species composition of the samples and the environmental parameters. First, the relatively small number of samples taken at each lake may have resulted in taxa being missed. The sparse species-samples matrix and the large number of samples with only two or three taxa may have skewed ordination results. Additionally, collecting data that included an abundance measurement for taxa might result in more sensitive ordinations than the current data which were based on species presence or absence. Moreover, sampling during the period of turnover from the winter flora to the summer flora may have obscured species-environment patterns that would otherwise exist. It also is possible that the limiting environmental factor(s) structuring the scaled chrysophyte and synurophyte community were not measured or that scaled chrysophytes and synurophytes are not strong indicators of environment in eastern Texas lakes within the measured ranges of the environmental parameters.

In conclusion, as has been demonstrated in other regions of the U.S., Texas contains a diverse flora of scaled chrysophytes. This investigation is by no means exhaustive, and it is believed that further collections and observations from eastern Texas and other Texas physiographic provinces will yield additional species and possibly clarify species-environment relationships. Including this paper, the silica-scaled chrysophytes known from Texas, based on electron microscopy, now comprise 33 taxa.

ACKNOWLEDGMENTS

The authors wish to thank M. Wujek for all aspects of the field collections, Alexandra Van Kley for her assistance in some of the field collections, P. Elsner for grid coating, K. Jeisel for some of the TEM observations, and CMU MultiMedia Production in helping with the
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**LITERATURE CITED**


Hill, M. O. 1979. DECORANA - a FORTRAN program for detrended correspondence analysis and reciprocal averaging. Cornell ecology programs, Department of Ecology and
ENZYMATIC VARIATION IN THE LAND SNAIL
EUGLANDINA TEXASIANA (GASTROPODA: PULMONATA)
FROM SOUTH TEXAS AND NORTHEASTERN MEXICO

Kathryn E. Perez* and Ned E. Strenth
Department of Biology, Angelo State University
San Angelo, Texas 76909
*Current Address:
Department of Biological Sciences
University of Alabama, P.O. Box 870345
Tuscaloosa, Alabama 35487

Abstract.—Enzymatic variation in four specimens of the land snail Euglandina

texasiana (Pfeiffer) from south Texas and northeastern México (150 km distant) was
examined using cellulose acetate gel electrophoresis. Ten of the 15 loci examined were
found to be monomorphic for all specimens. Considerable variation was observed to occur
in the remaining five loci. A computer analysis of the resulting enzymatic variation
revealed that specimens from these two locations were 94.5% genetically similar. A single
specimen of Euglandina singleyana (Binney) from New Braunfels in central Texas was
found to be 47.6% similar to specimens of Euglandina texasiana.

Resumen.—La variación enzimática en cuatro especímenes del caracol terrestre
Euglandina texasiana (Pfeiffer) del sur de Texas y del nordeste de México (a 150 km
distante) fue examinada usando electroforesis de gel de acetato celuloso. Se encontró que
diez de los 15 lugares examinados son monomórficos para todos los especímenes. Un
análisis de computadora de la variación enzimática resultante reveló que los especímenes
de estas dos localidades fueron el 94.5% genéticamente similares. Se encontró que un solo
especimen de Euglandina singleyana (Binney) de New Braunfels en Texas central es el
47.6% parecido a especímenes de Euglandina texasiana.

Two naturally occurring widespread species of the predaceous land
snail Euglandina are currently recognized from Texas. Euglandina

singleyana is reported from a large area of central Texas. It ranges
from Terrell County in the west to Fayette County in the east, and south
to Refugio County (Strecker 1935; Pilsbry & Ferriss 1906; Pilsbry

Euglandina texasiana inhabits areas of Hidalgo, Cameron and Willacy
counties in the Rio Grande Valley of south Texas (Pilsbry 1946;
341). These two species of Euglandina are allopatric and separated by
a zone of over 200 km.
Euglandina texasiana also inhabits a region of coastal lowlands in México which extends from the Rio Grande Valley south through Tamaulipas to eastern San Luis Potosí and northern Veracruz (Pilsbry 1907-08; 1946; Pilsbry & Vanatta 1936; Correa 1999; 2000; Correa et al. 1998). It also ranges westward to Nuevo León (Correa 1999). While northeastern México in general is characterized by the presence of numerous conspecifics (Pilsbry 1907-08; Pilsbry & Vanatta 1936; Correa 1993; 1996-97; 1999; 2000; Correa et al. 1998), these coastal lowlands of northern Tamaulipas appear to lack additional species and subspecies of Euglandina. Collections made during this study at both San Fernando and Soto la Marina yielded only specimens of E. texasiana.

This study was undertaken to examine and determine the level of enzymatic variation among specimens of Euglandina texasiana from two distant collection localities in south Texas and northern Tamaulipas. The collection site of San Fernando represents a location near the center of the distributional range of Euglandina texasiana in México. The selection of this collection location also appears to minimize any possible influence of the numerous additional species and subspecies which are present in areas to both the south and west of this region of northeastern México. In addition, these electrophoretic results are compared with those from a single specimen of E. singleyana from near its type-locality in central Texas.

It should be noted that the habitat of E. texasiana in south Texas is rapidly being eliminated due to agricultural clearing (Fullington & Pratt 1974; Neck 1984; 1988) and that Euglandina specimens in Texas are generally considered to be uncommon (Singley 1893; Neck 1984; 1988). As a result of their very specialized feeding habits, rarity, habitat preferences, as well as the results of human activities, the five specimens examined during this study represent a significant collection of living specimens of Euglandina. Additionally, Gorman & Renzi (1979) support the validity of the use of small sample sizes in electrophoretic studies such as this one.
Table 1. Enzymes with buffer system used. The buffer system used for all enzyme systems was Tris-Glycine pH 8.5. Recipe from Hebert & Beaton (1993).

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<thead>
<tr>
<th>ENZYME (E.C. NO.)</th>
<th>ABBREVIATION</th>
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<tr>
<td>Adenylate kinase (2.7.4.3)</td>
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<tr>
<td>Aspartate aminotransferase (2.6.1.1)</td>
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<td>AAT-2</td>
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<td>Catalase (1.11.1.6)</td>
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<tr>
<td>Glucose-6-phosphate Dehydrogenase (1.1.1.49)</td>
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<tr>
<td>Glucose-6-phosphate Isomerase (5.3.1.9)</td>
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<td>Glutamate Dehydrogenase (1.4.1.2)</td>
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<tr>
<td>Hexokinase (2.7.1.1)</td>
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<tr>
<td>Isocitrate Dehydrogenase (1.1.1.42)</td>
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<td>Malate Dehydrogenase (NADP+) (1.1.1.40)</td>
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<td>MDHP-2</td>
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<td>Mannose Phosphate Isomerase (5.3.1.8)</td>
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<tr>
<td>Phosphoglucomutase (5.4.2.2)</td>
<td>PGM</td>
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MATERIALS AND METHODS

Two specimens each of Euglandina texasiana were collected from Mission in Hidalgo County of south Texas and San Fernando (150 km distant to the south) in Tamaulipas, México. One specimen of Euglandina singleyana was collected from New Braunfels in Comal County of central Texas. A single specimen of Rabdotus alternatus from Nacimiento de Río Frío in Tamaulipas was selected as an outgroup.

Following collection, individual specimens were held without feeding for 7-10 days. They were then removed from their shells and the tissue was frozen in cryotubes in liquid nitrogen and stored at -80°C in an ultracold freezer until analysis. Samples of muscular foot tissue were homogenized in two volumes of distilled water using a glass rod and centrifuged to obtain an aqueous extract. Procedures for cellulose acetate electrophoresis followed those of Hebert & Beaton (1993). Gels were purchased from Helena Laboratories Inc. (Beaumont, Texas). The stain and buffer recipes used follow those of Shaw & Prasad (1970) and Hebert & Beaton (1993). The buffer used was Tris-Glycine pH 8.5. Scorable data for fifteen loci (Table 1) were obtained and analyzed using
the BIOSYS-1 computer program (Swofford & Selander 1981). To determine genetic similarity, Rogers’ genetic similarity (1972) was calculated. An unweighted pair group method using arithmetic averages (UPGMA) cluster analysis was then performed using Rogers’ genetic similarity matrix. The shells of all specimens examined during this study are deposited with the holdings of the Strecker Museum (SM) of the Mayborn Museum Complex of Baylor University.

MATERIAL EXAMINED

*Euglandina texasiana.*—Two specimens (SM 32449, 32450), Mission, Hidalgo County, Texas, 1 July 1992; two specimens (SM 32447, 32448), 5 km S of San Fernando, Tamaulipas, México, 20 May 1992.

*Euglandina singleyana.*—One specimen (SM 32451), New Braunfels, Comal County, Texas, 12 March 1991.

*Rabdotus alternatus.*—One specimen, Nacimiento de Río Frío (22 km NNW of Ciudad Mante), Tamaulipas, México, 24 May 1991.

RESULTS AND CONCLUSIONS

The results of this study (Figure 1, Table 2) reveal the presence of a moderately high degree of genetic similarity in all four specimens of *Euglandina texasiana* examined from both Texas and Tamaulipas. Ten
Table 2. Allele frequencies in specimens of *Euglandina texansiana* (San Fernando and Mission), *E. singleyana* and *Rabdotus alternatus* from Texas and México.

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of the 15 loci examined were monomorphic for all specimens; variation was observed in five loci (PGM, GTDH, HK, ADK, AAT-1). The two specimens from San Fernando were identical at 14 of the 15 loci and differed only when stained for hexokinase (Table 2). The two specimens from Mission exhibited a greater degree of variation than the San Fernando specimens with variation observed at four loci (GTDH, HK, ADK, AAT-1). An analysis of the resulting enzymatic variation (Figure 1) revealed that specimens from the two collection localities were 94.5% genetically similar. This overall genetic similarity of 94.5% for all specimens from both locations is well within the range expected for genetic variation within a single species (Quicke 1993) and compares with similar results in populations of Helix aspersa by Selander & Kaufman (1975) and Helicina orbiculata by Strenth & Littleton (2000).

The single specimen of Euglandina singleyana from central Texas was found to be only 47.6% genetically similar (Figure 1) to specimens of E. texasiana from south Texas and northern Tamaulipas. This low level of genetic similarity supports the validity of the results of earlier workers in maintaining the distinction and separation of these two species of land snails based upon differences in shell morphology and geographical distribution.

ACKNOWLEDGMENTS

The authors wish to thank the Beta Beta Beta organization for the research scholarship that provided financial support for this research. For help in procuring specimens we wish to thank Thomas G. Littleton, Dr. Brad C. Henry of UT Pan-American and Lynn McCutchen of Kilgore College. We also thank Dan Webb and John Beatty for laboratory assistance and Dr. Neil Devereaux for translation of the Spanish resumen.

LITERATURE CITED


KEP at: Kathryn_Perez@excite.com
Abstract.—Studies were conducted to assess the spatial learning ability of adults of *Sceloporus poinsettii*. Experimental design was such that it tested the ability (discrimination ratio, DR) of specimens to re-visit sites that had provided food on the previous day. DRs plotted as a proportion of correct responses were significantly greater than chance for all lizards, showing that these animals returned to a location where they had found food 24 hr earlier. This 24 hr period was longer than those previously reported for reptiles on other types of spatial learning tasks. The adaptive significance of spatial learning in lizards is discussed.

The ability of an animal to associate specific locations with the availability of food or some other required resource (spatial learning) would certainly contribute to its overall fitness. Spatial learning has been reported in fish (Reebs 1994), birds (Wilkie & Willson 1992) and mammals (Leonard & McNaughton 1990; Poucet 1993; Janson 1998), as well as insects (Punzo 1985a; 1996; Beugnon et al. 1996) and spiders (Punzo & Kukoyi 1997), but less information is available on amphibians (Brattstrom 1990; Punzo 1991) and reptiles (Burghardt 1977; Brattstrom 1978; Kirkish et al. 1979; Punzo 1985b; Holtzman et al. 1999). Spatial learning can significantly reduce the amount of time spent in random searching patterns and as a result maximize foraging activities (Stephens & Krebs 1986).

Previous research has suggested that reptiles learn and remember a variety of spatial tasks encountered under natural conditions. These include the location of water and food by turtles (Yeomans 1995) and snakes (Weatherhead & Robertson 1990), the location of escape routes in snakes (Holtzman et al. 1999), orientation and navigation in alligators (Rodda 1985) and lizards (Adler & Phillips 1985), location of conspecifics in lizards (Korning et al. 2000), and homing behavior in sea turtles (Lohmann & Lohmann 1996).

In the present study laboratory experiments were conducted to assess the ability of the crevice spiny lizard, *Sceloporus poinsettii*, to return to
a specific food source based on previous experience (spatial associative learning). This lizard typically inhabits rocky canyons, hillsides and outcrops of limestone or granite, as well as lava formations in mesquite grasslands and arid woodlands (Bartlett & Bartlett 1999). It is a wary animal that frequently perches on rocks and boulders, quickly retreating into crevices when disturbed.

**MATERIALS AND METHODS**

The subjects were seven adult male lizards (6 - 7 cm, SVL) that were raised as hatchlings in the laboratory. Their maternal parents \((n = 4)\) were collected from several locations in Big Bend Ranch State Park (Presidio County, Texas) in 1997. The lizards were housed separately in plastic cages and maintained on a diet of mealworm larvae and adults, as well as crickets, katydids, harvestmen and spiders.

The lizards were tested in a Plexiglass chamber (60 by 60 by 30 cm). The floor of the chamber was covered with a piece of synthetic turf grass carpeting. A small glass dish was placed on the floor at the center of each wall, and positioned so that it made contact with the wall. These dishes were used to provide food reinforcement during training sessions. All experiments were conducted in a room with no windows. A cool fluorescent light was positioned 120 cm directly above the center of the chamber. Under these conditions, the temperature on the floor of the chamber was 28° \(\pm\) 2°C, with a relative humidity of 65 - 72%.

In order to acclimate the lizards to the test chamber (pretrial sessions), two mealworm larvae (*Tenebrio molitor*, 12 - 15 mm in length) were placed in each dish, and each lizard was introduced separately into the center of the chamber (one at a time, with its head facing the east wall of the room) and allowed to feed from any dish of its choosing. These pretrial sessions (once per day) consisted of a period of 2 hr over a three-day period. The lizards typically ran from one dish to another, eating from two to five mealworms per session, and all of the lizards had visited each of the dishes at least twice over the course of three days. This feeding regime allowed the lizards to maintain their body weight at approximately 95% of their prior free-feeding weights. All lizards were deprived of food for 72 h prior to trials.

For all spatial associative learning trials each lizard received 25 daily sessions, and each session was divided into two stages. No food was available in any of the dishes during the initial stage. The lizard was
manually placed in the center of the chamber, and the initial stage began with the first visit to any food dish. This initial stage (which lasted an average of 90 sec) was considered terminated when a lizard made contact with a food dish with its snout. Data from these trials allowed an assessment of whether or not the lizards would continue to choose to visit a dish that had provided food during a previous session. In all experiments, observations on the lizards were made behind a one-way mirror so as to minimize distraction of the animals.

During the second stage of each session (lasting 30 min), only one dish (randomly chosen, using a table of random numbers) provided food each day. During each session a discrimination ratio was calculated for responses during the initial no-food period as described by Wilson & Wilkie (1993). The total number of visits made to the dish that had provided food on the previous day was divided by the total number of visits made to all four dishes during this period. This ratio is a measure of the animals’ tendency to persevere at the dish that provided food (positive reinforcement) on the previous day and can be used as an index of the animals’ capacity to remember place-food associations from day to day (Mistlberger 1994). In the absence of such memory, this ratio would be expected to have a value of 0.25. These discrimination ratios were expressed as the proportion of correct responses averaged over all training sessions for each subject. Significance was assessed using a Chi Square test (Sokal & Rohlf 1995).

**RESULTS AND DISCUSSION**

Figure 1 illustrates the discrimination ratios plotted as the proportion of correct responses averaged over all sessions for each lizard. These ratios are significantly greater than chance ($X^2 = 13.24, P < 0.01$). The results indicate that these lizards will return to a location (dish) where they had found food 24 hr earlier. This 24 hr period is longer than those previously reported for lizards (Burghardt 1977; Kirkish et al. 1979; Punzo 1985b) and other reptiles (Yeomans 1995; Ishida & Papini 1997) in other types of spatial learning tasks. This memory capacity compares favorably with results reported for birds and mammals (Sherry et al. 1992; Benhamou & Poucet, 1996).

For many animals, food availability may vary both spatially and temporally over the course of a day or several days. For example, prey may be more abundant at one particular location in the morning or afternoon. If this spatial and/or temporal pattern remains consistent on
a daily basis, an efficient forager should learn to visit those sites where prey abundance is highest. An even greater foraging efficiency could be attained by learning to visit a specific location during a particular time interval when food is more readily available, a behavior known as time-place learning (TPL). To date, TPL has been shown only in honey bees (Gould 1986) and ants (Beugnon et al. 1996), as well as some species of birds (Biebach et al. 1989; Wilkie & Wilson 1992) and mammals (Benhamou & Poucet 1996). This study shows that *S. poinsetti* learned to associate specific locations characterized by a higher probability of finding prey. Temporal aspects of learning have not yet been clearly demonstrated in reptiles and TPL should be further investigated in this group.

In experiments on reversal training, another type of spatial learning task, investigators had concluded that reptiles did not perform very well (Bitterman 1965; 1975). However, Kirkish et al. (1979) showed that the ability of the gecko, *Coleonyx variegatus* to learn a spatial reversal task was similar to that shown by birds. Thus, it appears that the capacity of reptiles to modify their behavior based on past experience (behavioral plasticity) is more highly developed than previously thought, and future studies should focus on other types of learning tasks that have ecological relevance.
The results of the present study also may suggest that under natural conditions, *S. poinsetti* may be expected to revisit locations where food was successfully procured on the previous day. Further work is needed to determine if these lizards will move to different patches when prey density falls below a certain level and capture rates decline over a certain period of time. Spatial associative learning allows foraging animals to revisit those locations which are most likely to obtain a source of food while minimizing the costs associated with search time.

**ACKNOWLEDGMENTS**

I thank two anonymous reviewers as well as R. A. Seigel and C. Bradford for commenting on earlier drafts of the MS. I also thank T. Punzo for his assistance in running some of the learning sessions and recording data, and the University of Tampa for a Faculty Development Grant which made much of this work possible. This research was conducted with the permission of the Texas Parks & Wildlife Department, Permit # 44-97.

**LITERATURE CITED**


Ishida, M. & M. R. Papini. 1997. Massed-trial overtraining effects on extinction and


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LONG-TERM STRUCTURAL HABITAT USE OF MALE INDIVIDUALS OF TWO NATIVE AND ONE INTRODUCED ANOLIS (IGUANIDAE) SPECIES ON THE NORTH COAST OF JAMAICA

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Abstract.—This study compares the perch heights and densities of male Anolis grahami, A. sagrei and A. lineatopus at four localities near Ocho Rios, Jamaica during the spring of 1983, 1987, 1994, 1996, 1998 and 2000. This is the first report of an Anolis perch height study sampling the same study area for a period of almost two decades. The finding of stability over the long-term in this system lends validity to numerous short-term studies. Data analyses included assessment of perch height and densities. Mean perch heights were significantly different among species during the study. However, there was still significant overlap in this niche dimension in many years of the study. Anolis sagrei is an invader that has integrated into the Anolis community at this locality. Implications of these findings are discussed regarding reasons for coexistence and potential competition between these species.

Community structure may arise by both rapid processes occurring in ecological time, as well as by more long term processes acting over evolutionary time (Roughgarden et al. 1983; Grant 1986). Communities may be structured by invaders, where to be successful as a colonist, an invading species must be pre-adapted to fit in with other members of the community (Rummel & Roughgarden 1983; 1985), or structured through mutual co-adaptation of community members (Beuttell & Losos 1999). Caribbean Anolis lizards provide good model systems for analyzing community structure because of their simplicity, ease of observation, and because anoles are likely to be relatively insensitive to unobtrusive observation (Sugerman 1990). However, the extent to which such communities are the result of coevolution among species is ambiguous (Williams 1972; Roughgarden et al. 1989; Losos 1992a; 1992b; Butler et al. 2000). Investigation of the effects of invasion by Anolis sagrei may provide insight into the evolution of Anolis communities in the Caribbean. This is the first long-term report in the literature studying the Anolis community structure at the same study area for nearly two decades.

This study examines perch heights and densities of three common Anolis species (Anolis grahami, A. sagrei and A. lineatopus) at four
localities of a study site on the north coast of Jamaica (see Underwood & Williams 1959 for a complete description of these species). Rand (1964) originally used perch height and perch diameter to distinguish the spatial niche dimensions used by the anole species that he studied, and other authors have used these measures to quantify habitat use (Schoener, 1967; Schoener & Schoener 1971; Losos et al. 1993). Spatial habitat use has also been described by perch type and by the degree of insolation (Schoener & Schoener 1971; Losos et al. 1993). Perch height may be the most conveniently quantified measure of structural habitat because these characteristics are correlated with other habitat features and, if partitioned between or within species, will allow a large number of lizard species to coexist in a relatively small area. For example, in studying five Anolis species at three lowland localities on Jamaica, Schoener & Schoener (1971) found that anoles have partitioned their spatial niches to reduce spatial overlap and avoid potential intraspecific and interspecific competition. Results of these studies have led to the classification of Anolis lizards into different ecomorph classes (Butler et al. 2000).

Because A. sagrei is a successful invader that is part of the landscape at these localities and is expanding its range across the island (Underwood & Williams 1959; Williams 1969; Mayer 1989; Schwartz & Henderson 1991), there is reason to expect changes in the Anolis community. This study quantifies perch height and examines density of male Anolis species and compares these data among the species.

MATERIALS AND METHODS

Observations were made at the Hofstra University Marine Laboratory campus at Priory, Saint Ann’s Parish, Jamaica, West Indies. The study began in March 1983, but these data were not included in the analysis because it was a project development year. Data were collected on 10-13 March 1987, 4-9 January 1994, 16-22 March 1996, 16-20 March 1998 and 13-25 March 2000 between 0800-1800 hours from four localities on the campus. Each locality represented a study area that included a beach and three highly disturbed areas. The disturbed areas included laboratory buildings, concrete walls, telephone poles, a barb wire fence, lumber and brick piles and a low wooden pier. Flora present in all of these areas included red mangrove, coconut and banana trees and several varieties of cultivated garden plants. The study areas were termed "Beach", "Executive Suite", "Boathouse" and "Driveway".
Potential habitat availability and maximum available perch heights were similar in all of these study areas.

One to four observers carefully searched each study area several times during the day. The junior author participated in data collection in all study years and the senior author participated in 1987 and 2000. When a lizard was observed, its perch height and perch diameter was recorded by tape measure to the nearest cm. Lizards observed on the ground were assigned a perch height of zero. Only large, adult males were used in the study because they are larger and more conspicuous due to their social dewlap displays. Several other studies on Anolis have focused exclusively on adult males (Rand & Williams 1969; Williams 1972; 1983).

Perch data were used to calculate and compare mean perch heights for each species within each year of observation. Lizard densities were also calculated for all study areas in all years that observations were made. Perch heights between species for each year were compared using one-way ANOVA. When the same data were used in pairwise multiple comparisons (LSD Tests), sequential Bonferroni correction (alpha = 0.05) was used to judge statistical significance (Rice 1989). Probabilities reported remain significant with the Bonferroni correction.

RESULTS

The mean perch heights for each Anolis species during all years of the study are shown in Fig. 1. One-way ANOVA tests indicate highly statistically significant differences in perch heights within years among all three species during each year of the study (1987 $f=34.167$, $P<0.0001$; 1994 $f=14.938$, $P<0.001$; 1996 $f=12.216$, $P=0.001$; 1998 $f=16.960$, $P<0.001$; 2000 $f=16.900$, $P<0.001$).

Multiple comparisons using post-hoc LSD with sequential Bonferroni correction indicated many significant differences in perch height between species for each year of observation (Table 1). Anolis grahami tended to occupy the highest perches compared to the other species studied, with A sagrei occupying the lowest and A. lineatopus occupying a mid-range perch height. In every year of the study, A. grahami occupied significantly higher perches than A. sagrei, but A. grahami’s mean perch height was significantly higher than A. lineatopus only in 1987, 1998
Figure 1. Mean perch heights and standard errors for male *Anolis grahami*, *Anolis lineatopus* and *Anolis sagrei* from observations taken between 1987 - 2000.

and 2000 (Table 1). *Anolis lineatopus* occupied significantly higher perches than *A. sagrei* in 1994, 1996 and 2000 (Table 1).

Observed densities of the three *Anolis* species across all sites were similar and not significantly different from one other across years of the study. Density data are shown for all years of the study in Table 2.

**DISCUSSION**

The data analysis results show that there are statistically significant differences among these species in perch heights. However the degree of perch height overlap varies by year (Fig. 1) and only *A. grahami* and *A. sagrei* show significantly different mean perch heights at these localities in every year studied. The reasons for this variation is not entirely clear and because of this result, it may be useful to examine other niche axes, such as degree of insolation or temperature, to explain the coexistence of these species. Statistical differences in perch heights may not solely be biologically meaningful measures of habitat use because they do not adequately or accurately represent the structural
Table 1. Differences in perch height between species for each year of observation 1987-2000. Mean values with asterisks (*) are significantly different than mean values without asterisks based on post-hoc LSD tests with sequential Bonferroni correction ($P<0.05$).

<table>
<thead>
<tr>
<th>Year</th>
<th>Anolis grahami (cm)</th>
<th>Anolis lineatopus (cm)</th>
<th>Anolis sagrei (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>229.62</td>
<td>90.75*</td>
<td>69.31*</td>
</tr>
<tr>
<td>1994</td>
<td>142.15*</td>
<td>114.14*</td>
<td>58.08</td>
</tr>
<tr>
<td>1996</td>
<td>125.64*</td>
<td>101.93*</td>
<td>34.54</td>
</tr>
<tr>
<td>1998</td>
<td>152.84</td>
<td>61.87*</td>
<td>75.71*</td>
</tr>
<tr>
<td>2000</td>
<td>162.72</td>
<td>99.23</td>
<td>53.93</td>
</tr>
</tbody>
</table>

niche of a lizard. Other niche axes such as degree of thermal preference, and/or finer scale habitat measures may be needed to fully quantify habitat use. For example, thermal preference data taken from *Anolis* at these sites in 1996 and 1998 show that *A. grahami* is a thermo-regulator that prefers to bask in the sun while *A. lineatopus* is a thermo-conformer (Huey & Webster 1976) and prefers more shaded habitats.

*Anolis* densities were similar in all years of this study and although there was a trend towards *A. sagrei* having the highest density, its density was not significantly different than that of the other species. Those factors which allow these species to coexist remain unresolved. There may be ecological differences among these species. For example, *A. sagrei* exhibited tremendous phenotypic plasticity in hindlimb length when raised under laboratory conditions in different structural habitats leading to phenotypes well adapted to particular environments (Losos et al. 2000). Such plasticity is likely to be advantageous to these colonists both in getting established and in subsequent persistence. Pre-invasion body-size differences may affect the size of prey items consumed by these lizards (Schoener 1967; Roughgarden 1974; but see Floyd & Jenssen, 1983). Also, other unmeasured niche axes on which these species may be very different in their overlap include differences in insolation and preferred body temperatures. *Anolis lineatopus* was observed far more frequently in the shade than the other two species, and hence may not compete with the other species for shady perches. Cuban and Floridian *A. sagrei* are thermophilic and utilize sunny low habitats (Ruibal 1961; Salzburg 1984). In this study, *A. sagrei* and *A. grahami* were both seen frequently at these types of sites and especially on the beach in direct sunlight. Hence, preferred body temperatures
Table 2. Mean densities of three Anolis species during all years of the study. Data are mean numbers of male lizards observed per census across all sites.

<table>
<thead>
<tr>
<th>Year</th>
<th>Anolis grahami</th>
<th>Anolis lineatopus</th>
<th>Anolis sagrei</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987</td>
<td>3.4</td>
<td>1.1</td>
<td>5.3</td>
</tr>
<tr>
<td>1994</td>
<td>3.9</td>
<td>1.9</td>
<td>7.7</td>
</tr>
<tr>
<td>1996</td>
<td>2.6</td>
<td>1.3</td>
<td>4.8</td>
</tr>
<tr>
<td>1998</td>
<td>2.5</td>
<td>1.3</td>
<td>5.9</td>
</tr>
<tr>
<td>2000</td>
<td>4.2</td>
<td>2.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

may differ and prevent overlap among these species. All of these factors may allow the coexistence that is currently observed in this Anolis community. Long-term studies like this one are essential in understanding community structure and the observed stability at this study area for almost two decades validates numerous short-term studies.

Future studies should involve detailed microhabitat use quantification and account for other important niche axes that may help to understand the ecological and ultimately the evolutionary factors that are responsible for Anolis community structure. Such information may be useful in predicting the outcome of invasions on lizard community structure. Finally, it must be noted that conclusions reported herein about competitive effects must remain tentative in the absence of data on the entire marked populations, data from controlled field manipulations, and data on the effects of climate, resource availability, and the ongoing habitat disturbances on these species. Such thorough investigations are necessary to reveal post-invasion responses to interactions among these species.

ACKNOWLEDGMENTS

We are grateful to Melissa Garretson, Mark Brewer, Amy Foster, Natalie Stevens, Heather Terrill, Todd Harris, Bill Gehrmann and Kris Karsten for help with lizard observations and perch height measurements. We thank Roy Vogtsberger for critiquing the manuscript and thank the Hofstra Marine Station officials and personnel, including Eugene Kaplan, Deb Bidwell and Gorka Sancho for making this study possible. We also thank Joe Darnall for statistical advice.

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LITERATURE CITED


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HABITAT UTILIZATION BY EASTERN YELLOWBELLY RACERS  
(COLUBER CONSTRIC TOR FLAVIVENTRIS) IN  
SOUTHWEST DALLAS COUNTY, TEXAS  

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Abstract.—A population of Coluber constrictor flaviventris was surveyed in both relic  
and disturbed Blackland Prairie habitats during the spring, summer and fall of 1999 and 2000  
at Cedar Hill State Park in Dallas County, Texas. Drift fences with funnel traps and  
coverboards were used to live-trap snakes. During the two years, 69 specimens were  
recorded. The study demonstrated that the disturbed Blackland Prairie had significantly more  
specimens then the relic Blackland Prairie.  

There are several publications discussing reptiles and amphibians  
utilizing and adapting to disturbed habitats (Dyrkacz 1977; Enge 1998;  
Fitch 1999; Kaufmann 1992.). Bury (1983) reported that the amphibian  
populations in an old growth forest (both species richness and abundance) were drastically altered after logging had occurred. However,  
comparisons of reptiles or amphibians utilizing both relic and disturbed  
habitats of the same habitat type are uncommon.  

Coluber constrictor is found in a variety of habitats throughout the  
United States including grasslands, prairies and forested areas (Conant  
& Collins 1998). In Cedar Hill State Park, where C. constictor flaviventris occurs, they are abundant in these habitats but were noted to  
exhibit a strong tendency towards grasslands. Coluber constrictor are  
strictly diurnal with a relatively high body temperature preference (Fitch 1999). Their diet consists of a large variety of food items including  
insects, reptiles, amphibians and rodents in adult specimens (Fitch 1999). This study compares habitat usage by Coluber constrictor flaviventris in both relic and disturbed prairie habitats.  

STUDY SITE  
Cedar Hill State Park is located in southwest Dallas County and  
encompasses 1826 acres of disturbed prairie, relic prairie, oak forest and  
disturbed hillside forest. Adjacent to the park is Joe Pool Lake, which  
was created in 1981 for water consumption by the Dallas/Fort Worth  
metroplex residents. The topography is gently rolling hills except for
steep west-facing bluffs associated with a chalk outcrop of the White Rock Escarpment (Carr 1993). Elevation varies from 115 m in the prairies to 250 m on the escarpment. The two habitats studied were relic Blackland Prairie (RBP) and disturbed Blackland Prairie (DBP).

The RBP (32° 37'N, 96° 60'W) is characterized by nearly level to gently rolling hills with extremely fertile soil. The soil of the Blackland Prairie within the park is considered deep, moderately well drained, moderately alkaline and contains black calcareous clay (Coffee et al. 1980). The blackland habitat is true tallgrass prairie, with the little blue-stem (Schizachyrium scoparium) as the climax dominant vegetation (Simpson 1998). This relatively undisturbed habitat has never been plowed or grazed by livestock and is maintained with controlled burns every three to five years.

DBP (32° 36'N, 96° 60'W) is similar to RBP in that the soil content and elevation are comparable. However, DBP has been grazed by livestock and the soil was once extensively farmed. The year of the last disturbance on this habitat was ca. 1980. At present, the habitat consists of mostly introduced grasses or non-woody native and introduced weeds. No dominant weed species could be discerned. There are no controlled burns in the disturbed prairie. Because of this the vegetation is much thicker and higher than that of the relic prairie.

**METHODS AND MATERIALS**

Within both habitat types, four 50 m² plots were established. These plots were approximately 20 m from the edge of any other plots. All plots were no less than 50 m from an adjacent habitat edge to avoid sampling species utilizing edge habitat. In the DBP, an unpaved park road measuring four meters wide divides a portion of the habitat sampled. One drift fence made of aluminum flashing measuring 15.5 m long and 0.5 m high was erected in the center of each of the four plots within each habitat type. A funnel trap measuring 60 cm by 25 cm was used at both ends of each drift fence. Due to the lack of shade and the heightened chances of a snake exceeding its thermal limit while confined in a funnel trap, boards (approximately the same size as the traps) were placed on top to provide shade. In addition to the plots, four-one m² cover boards were placed on the prairie ground. These cover boards were placed 10 m from the drift fences. While checking traps, visual searches were conducted on the way to and from the traps. If specimens were observed within these plots, they were recorded from that habitat type.
Table 1. Numbers of individual specimens of *Coluber constrictor flaviventris* collected in relic Blackland Prairie and disturbed Blackland Prairie habitats during the spring, summer and fall of 1999 and 2000 in Dallas County, Texas.

<table>
<thead>
<tr>
<th></th>
<th>Spring</th>
<th>Summer</th>
<th>Fall</th>
<th>Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relic Blackland Prairie</td>
<td>1999 (3)</td>
<td>1999 (1)</td>
<td>1999 (1)</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>2000 (4)</td>
<td>2000 (2)</td>
<td>2000 (1)</td>
<td>7</td>
</tr>
<tr>
<td>Disturbed Blackland Prairie</td>
<td>1999 (18)</td>
<td>1999 (2)</td>
<td>1999 (7)</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>2000 (17)</td>
<td>2000 (4)</td>
<td>2000 (9)</td>
<td>30</td>
</tr>
</tbody>
</table>

All traps were checked three times per week in the spring (April – mid June), once a week during the hotter summer months (Mid June – 1 September) and twice a week in autumn (September – 1 December), for both years. The traps were checked a total of 134 days during the two years. Specimens were tagged with passive integrated transponders (pit-tags) to record recaptures. Recaptures were not included in the data presented in this study.

**RESULTS AND DISCUSSION**

In 1999, five specimens were captured in the RBP, compared to 27 specimens in the DBP for a total of 32 specimens. The number of captures between the two habitats were significantly different ($\chi^2 = 15.2, P<0.01$). In year 2000, seven specimens were captured in the RBP, compared to 30 specimens in the DBP for a total of 37 specimens. Captures between the two habitats was again significantly different ($\chi^2 = 14.3, P<0.01$). For the two years sampled, a considerably higher number of *C. constictor flaviventris* were captured in the disturbed habitat compared to the relic habitat (Table 1).

Fitch (1999) reported that formerly cultivated fields, woodlands and open pastures that were heavily grazed by livestock had very few *C. constrictor*. However, when the grazing ended and the grasses returned the *C. constrictor* population size increased for several years (Fitch 1999). The disturbed habitat in this study was observed as being considerably more dense with meter high vegetation, which created more ground cover than that of the relic habitat. In addition, there was man-made debris in the form of lumber and old car tires in the disturbed habitat only. This debris was approximately 100 m from any of the four plots sampled. Two different species of rodents were observed in the DBP and three different species were found in the RBP. However, much larger numbers of rodents were observed in the DBP compared to
the RBP. Insects appeared in be more common in the DBP as well. Further studies on the prevalence of food items and/or vegetative cover within these two habitats needs to be undertaken in order to determine the importance of these factors in contributing to the differences in the number snakes observed.

ACKNOWLEDGEMENTS

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LITERATURE CITED


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EFFECTS OF TEMPERATURE AND LIGHT ON CHINESE TALLOW (SAPIUM SEBIFERUM) AND TEXAS SUGARBERRY (CELTIS LAEVIGATA) SEED GERMINATION

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Abstract.—Experiments were performed to assess germination requirements of seeds of Chinese tallow (Sapium sebiferum (L.) Roxb.) and Texas sugarberry (Celtis laevigata Willd.). Sapium and Celtis seeds were exposed to different combinations of light and temperature. It was predicted that Sapium would germinate under a variety of environmental conditions, but Sapium seeds germinated predominantly in fluctuating temperature conditions. Celtis seeds also germinated readily in such conditions but had less restrictive germination requirements. Since Celtis appears to be better adapted to a variety of germination conditions, a broader range of environmental germination tolerances does not explain Sapium's greater establishment success as an alien invader. Nevertheless, seeds requiring oscillating temperatures to germinate are most commonly found in canopy gaps or open areas suggesting that Sapium invasions may be especially problematic in disturbed habitats.

Chinese tallow tree (Sapium sebiferum) is an invasive deciduous tree species in ecosystems throughout the southeastern United States. Originally from Asia, it has extended its distribution considerably throughout the southeastern United States since its introduction in 1772 (Bruce et al. 1997; Barrilleaux & Grace 2000). Sapium displaces many plant species and drastically alters community structure by transforming native grasslands and other habitats into monospecific woodlands (Harcombe et al. 1993; Bruce et al. 1995; Grace 1998). The objective of this study was to assess the effects of light and temperature on seed germination of Sapium and an ecologically similar native, Texas sugarberry (Celtis laevigata). Celtis and Sapium are both small deciduous, fast growing trees that are insect pollinated and have bird dispersed seeds (Van Auken & Lohstroh 1990; Jubinsky & Anderson 1996; Renne et al. 2000). In the absence of proper management regimes, Celtis may also invade grassland ecosystems (Van Auken & Bush 1990; Harcombe et al. 1993).

Understanding what factors control Sapium germination is necessary for understanding the success of this invasive species and may provide insights for managing its growth at early developmental stages. Studying germination of Celtis in conjunction with Sapium provides a model for comparison with an ecologically similar native species. Germination
requirements for *Sapium* seeds were predicted to be governed less by environmental conditions than *Celtis* seeds and these differences were expected to partially explain the success of *Sapium* as an alien invader.

**MATERIALS AND METHODS**

*Sapium sebiferum* and *Celtis laevigata* seeds were collected from several uncultivated trees at the University of Houston Coastal Center in Galveston County, Texas in December 1999. Seeds were stored in the dark at room temperature for two months. In February 2000, seeds were planted in subdivided germination trays lined with a thin layer of peat moss and then filled with a mixture of 2/3 commercial top soil and 1/3 humus. Seeds of each species were randomly assigned to a temperature treatment (hot, cold and cycling) and a light treatment (light, dark and cycling) in a full-factorial design. Within each treatment, pairs of *Sapium* and *Celtis* seeds were randomly assigned to one of 240 cells (2 cm by 2 cm by 5 cm deep) in germination trays. The trays were kept in a temperature controlled room without windows for the duration of the experiment.

Seeds in the hot treatment were warmed with a germination mat that maintained the soil at a constant 32°C. Seeds in the cold treatment were kept constant at 16°C. Seeds in the cycling temperature treatment were subjected to 16 h of 32°C and 8 h of 16°C daily. Seeds assigned to the light treatment received 24 h of continuous light supplied by commercially available wide-spectrum plant grow lights suspended 20 cm above the tray surface (average PAR = 50 μmol/m²/sec). The cool fluorescent bulbs in the cold room emitted a negligible amount of heat that was unlikely to influence soil temperatures. Seeds in the dark treatment were kept dark 24 h per day. Although the dark treatments were isolated by opaque barriers, they were periodically exposed to low levels of diffuse light. Seeds assigned to the light cycle received 16 h of light and 8 h of dark per day. The temperature and light cycles were synchronous. All treatments were lightly watered and checked for germination daily. Newly germinated seeds were removed from their cells. The experiment was conducted for 175 days, but no seeds germinated after 120 days.

Separate Kruskal-Wallis nonparametric tests (i.e. nonparametric ANOVAs) were used to examine the effects of temperature treatment and light treatment on *Celtis* and *Sapium* germination (Statview 5.0, SAS Institute). Each cell was treated as an experimental unit and it was assigned a value of "yes" if a seedling germinated and a value of "no" if no seedling germinated in the cell.
Table 1. Separate Kruskal-Wallis nonparametric tests for dependence of the probability of a seed germinating in a cell for (a) *Sapium sebiferum* and (b) *Celtis laevigata* in response to temperature treatments (continuous cold, temperature-cycle, continuous heat) and light treatments (continuous dark, light/dark-cycle, continuous light).

<table>
<thead>
<tr>
<th>Species</th>
<th>Factor</th>
<th>df</th>
<th>adjusted H</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) <em>Sapium</em></td>
<td>Temperature</td>
<td>2</td>
<td>83.7</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>2</td>
<td>8.2</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>(b) <em>Celtis</em></td>
<td>Temperature</td>
<td>2</td>
<td>375.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td></td>
<td>Light</td>
<td>2</td>
<td>36.0</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

**RESULTS**

A significantly higher proportion of *Sapium* seeds germinated in the temperature-cycle treatment (Table 1, Figure 1a). Germination in the hot treatment and the cold treatment were extremely low. Within the temperature-cycle treatment, more *Sapium* seeds germinated in constant light and constant dark treatments than the light-cycle treatment (Figure 1a). Likewise, a significantly higher proportion of *Celtis* seeds germinated in the temperature-cycle treatment (Table 1, Figure 1b). Germination of *Celtis* in constant temperature treatments was lower than the temperature-cycle treatment, but some constant temperature and light combinations had moderate levels of germination (Figure 1b). Within temperature treatments, *Celtis* germination tended to be higher as light levels increased. *Sapium* germination was lower than *Celtis* germination in all treatment combinations (Figure 1).

**DISCUSSION**

Germination requirements for *Celtis* and *Sapium* appear to be primarily affected by fluctuating temperatures. For both species, germination in the temperature-cycle treatment far exceeded the combined germination total in continual cold and continual heat treatments. Light treatments also had a significant, albeit less prominent, effect on germination. *Celtis* seeds appeared to have less restrictive germination requirements than *Sapium* seeds. This contrasted with predictions that *Sapium*'s success as an invader may be partially due to a greater breadth of acceptable germination conditions than similar native woody species.

Many plant species use temperature fluctuations to monitor seasonal changes and assess growing conditions (Fenner 1985; Baskin & Baskin 1989). Additionally, soil and canopy vegetation can insulate seeds against daily temperature fluctuations under natural conditions. Adequate temperature fluctuations likely indicate appropriate burial depth and microhabitat conditions for successful establishment and new seedling growth (Fenner 1985; Baskin & Baskin 1989). For these reasons,
oscillating temperatures may be an important environmental cue for germination of *Celtis* and *Sapium* seeds.

While both *Celtis* and *Sapium* germination were highly dependent on temperature fluctuations, there were notable differences in germination responses between the two species. *Sapium* germination in constant heat and constant cold treatments was negligible, whereas *Celtis* seeds germinated with a comparatively greater frequency in constant temperature conditions. These results suggest *Celtis* has a greater total germination
rate and is able to germinate across a broader range of environmental conditions than *Sapium*. This outcome was surprising based on the ability of *Sapium* seedlings to thrive in a variety of light and soil resource conditions (Jones & McLeod 1990; Rogers et al. 2000). The high occurrence of *Sapium* germination in the constant darkness/temperature-cycle treatment suggests it does not have a light requirement for germination. Conversely, *Celtis* germination always increased when exposed to continuous light, particularly in the constant cold treatment.

In a separate study of *Sapium* germination requirements, Conway et al. (2000) investigated whether germination depended on seed imbibition and cold stratification. This was tested by subjecting *Sapium* seeds to varying soaking and chilling regimes. Very low germination rates for *Sapium* seeds were found and no differences among soaking and chilling treatments were detected (Conway et al. 2000). The present study indicates that oscillating heat, rather than cold stratification, may be more important for releasing seed dormancy. It is likely that no combination of soaking and chilling will significantly affect germination without adequate temperature fluctuations. Similar to Conway et al. (2000), seeds in the present study that were watered and subjected to a continually cold environment did not germinate. In another study of *Sapium* germination, Cameron et al. (2000) found that *Sapium* seeds maximally germinated in a greenhouse during January and February. Since *Sapium* germination peaks between April and May in field conditions, it is possible that the earlier germination period observed was due to elevated greenhouse temperatures.

*Sapium*'s success as an alien invader does not appear to be explained by having less restrictive germination requirements than similar native woody species. Nevertheless, it is likely that the conditions for releasing *Sapium* seed dormancy, temperature fluctuations, are commonplace in most natural environments. Combined with a high seed output (Scheld et al., 1984), seedling tolerance of varied environmental conditions and an apparent absence of insect herbivores (Jones & Sharitz 1989), *Sapium* invasion of multiple Gulf Coast habitats will remain problematic. This is particularly true of recently disturbed areas where the temperature fluctuations necessary for *Sapium* seed germination are more frequent (Fenner 1985; Baskin & Baskin 1989). Moreover, the role of long-term seed dormancy leading to the build-up of a persistent seed bank and the effect this has on *Sapium* invasion merits further study.

**ACKNOWLEDGMENTS**

We would like to thank the University of Houston Coastal Center for permission to collect *Sapium* and *Celtis* seeds. June Keay, Carrie Smith
and Ellen Wan provided valuable assistance. Two anonymous reviewers provided helpful suggestions to improve this manuscript.

**LITERATURE CITED**


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UPSTREAM CHANGES AND DOWNSTREAM EFFECTS OF THE SAN MARCOS RIVER OF CENTRAL TEXAS

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Abstract.—Changes in the headwaters of the San Marcos River, with an area of 247 km$^2$, have caused major sedimentation and exotic plant invasion problems in its course through the city of San Marcos. Construction of upstream flood control dams, with insufficient flow-through provisions, has reduced the effective unregulated upstream drainage to 47 km$^2$ and reduced mean annual flood from 510 m$^3$/sec (18,000 ft$^3$/sec) to 42 m$^3$/sec (1,500 ft$^3$/sec) which is less than the threshold value required for scouring the river channel. Headwaters area construction downstream of the flood control structures, particularly on the Southwest Texas State University campus, has increased sediment production from 160 m$^3$/year to 920 m$^3$/year. Since 1990, the combined effects of these changes have produced up to 0.50 m sedimentation in the main channel and an increase in exotic riparian and aquatic vegetation. Of the remedial actions proposed, the only likely option involves increased efforts to reduce sediment production from construction sites. The October 1998 flood, triggered by a larger than 100-year precipitation event (401mm/24hr), demonstrated that the flood control structures reduced peak discharge in San Marcos to a discharge that would have been approximately a twenty-five year event. This event did not produce the sediment scour that would have been expected which suggests that sediment increases and not a reduction of flows are the major cause of the sedimentation.

San Marcos, Texas, like many rapidly growing Sunbelt cities, faces the often conflicting goals of protecting aesthetic and recreational resources while providing flood protection. In 1970 the city had a population of 18,900; the 1995 estimate was 37,000 (City of San Marcos 1996) and the 1999 estimate was 41,000 (Greater San Marcos Economic Development Council 2000) even though the "official" 2000 census value was 34,733, which has prompted a city drive for a higher readjusted value (U.S. Bureau of the Census 2001). Southwest Texas State University (SWT), totally within the city limits, has grown from 9,900 students in 1970 to more than 22,000 in 2000 (Southwest Texas State University 2001). The San Marcos River was singled out in the 1996 city comprehensive plan as a unique resource that needs to be protected for the aesthetic benefit of residents and as a basis of the city’s tourism industry (City of San Marcos 1996). Each year, the San
Marcos River draws more than an estimated five hundred thousand visitors for water based recreation and civic activities adjacent to its banks (Greater San Marcos Economic Development Council 2000). Baseflow for the river flows from springs draining the Edwards Aquifer; floodflow is produced by a 247 km$^2$ headwaters with ephemeral flow.

Management and protection of the San Marcos River not only is motivated by concern for its benefit to the city; it is habitat to four federally listed endangered species, two fish, a salamander and Texas wild rice (Texas Parks and Wildlife Department 1993). In response to a 1992 federal court order to develop a habitat protection plan, the State of Texas has created the Edwards Aquifer Authority that has imposed pumping limits and has developed additional drought management pumpage restrictions (Votteler 1998). Characteristic of its location along the Balcones Escarpment, the San Marcos River has the potential for generating huge flood discharges (Baker 1975). The flood of May 15, 1970, which had an estimated discharge of 2,170 m$^3$/sec (76,600 ft$^3$/sec), resulted in two drownings and the city being declared a federal disaster area (Upper San Marcos Watershed Reclamation and Flood Control District 1991).

The 1970 flood was the stimulus for efforts to create the Upper San Marcos Watershed Reclamation and Flood Control District (USMWRFCD) in 1971. A flood on June 13, 1981 that forced the evacuation of 1,800 people provided the political catalyst for the funding of US Soil Conservation Service flood control dams upstream of San Marcos. The last of five flood control dams on the upper San Marcos watershed was completed in 1991 (USMWRFCD 1991). These dams have a combined capacity of 23 million m$^3$ (19,000 acre feet) and reduced the uncontrolled drainage area from 247 km$^2$ to 47 km$^2$. (U.S. Soil Conservation Service 1978). Construction in the upstream area, but mostly downstream of the flood control dams, has produced sedimentation in the perennial flow reaches of the river in San Marcos (Miller 1996). Also, the public has increasingly complained about clogging of the channel by vegetation (Wood 1998). The flood control project received a major test in October 1998 when a storm with an official San Marcos 24-hour total of 401 mm (15.78 in) produced runoff amounts that exceeded the 254 mm (10 in) standard project flood design and produced considerable flooding in San Marcos (U.S. Soil Conservation Service 1978; U.S. Natural Resources Conservation Service 1999).
The purpose of this paper is to report on the changes in the headwaters of the San Marcos River and their downstream effects, both planned for and unplanned, since the construction of the five upstream flood control structures that began in 1981. A particular focus of this paper will be the effects of these flood structures on the October 1998 flood. Not included in this analysis are effects of the damming of San Marcos Springs in 1849 to form Spring Lake, which was developed into the popular commercial site known as Aquarena Springs (Mays et al. 1996), nor will this paper analyze the effects of the construction of small irrigation and hydroelectric dams (Rio Vista and Cape's Camp dams) downstream of San Marcos Springs during the late 1890s and early 1900s (McGehee 1982; Stovall 1986; Spain 1994). This paper is intended to complement the recent study on water quality characteristics of the San Marcos River by Groeger et al. (1997) and contains updated bibliographic references to augment those in Saunders (1992).

**METHODS AND MATERIALS**

After describing the basic hydrology of the upper San Marcos River basin, this paper will analyze the changes in the watershed since 1970 and the efforts to mitigate the flood hazard and also summarize the discharges generated by the October 1998 event in upstream tributaries as well as the main channel in San Marcos. An analysis of the flood frequency of the modern stream will provide for an assessment of the stream's ability to transport the increased sediment supply that construction within the basin has produced. A series of management options for the stream under its new regime of reduced peak discharges and high sediment production will also be presented. Major data sources include the flood control project (U.S. Soil Conservation Service 1978; USMWRFC 1991) and discharge data for the San Marcos River from the U.S. Geological Survey (USGS) gaging stations in San Marcos (USGS 1921; 1956-1999). Basic surveying methods were used to measure channel geometry and metal rod penetrometers to measure sediment depth to the nearest 0.1 m (Goudie 1990; Wood & Gilmer 1996). Currently available models were used for the calculation of hydrologic relationships for the basin and the channel. These included the Universal Soil Loss Equation model, which calculates annual sediment yield as a function of basin characteristics and the U.S. Soil Conservation Service TR 55 Runoff model, which calculates storm runoff as a function of storm intensity and basin characteristics, (Dunne & Leopold 1978; US Soil Conservation Service 1986; Chow et al. 1988; Dingman
The U.S. Geological Survey Slope-Area method (Dalrymple & Benson 1967) was used to estimate peak discharge at ungaged sites for the October 1998 storm.

THE SAN MARCOS RIVER BASIN

The study area includes the 247 km² area within the Upper San Marcos Watershed Reclamation and Flood Control District (USMWRFCD) which includes the entire drainage of the San Marcos River upstream of its confluence with the Blanco River approximately 3 km southeast of Interstate Highway I-35 (Fig. 1). Discharge data for the basin has been provided since 1956 by U.S. Geological Survey (USGS) gage no. 08170000, which has been located at several sites along the river between the confluence with the Blanco River and downtown San Marcos, approximately one kilometer west of I-35 (Fig. 1). In 1994 the USGS installed another gage (08170500) where the river crosses under Aquarena Drive, approximately 1.5 kilometer west of I-35. This latter gage provides direct measurement of discharge whereas the original gage (08170000) was replaced by a well monitor in 1988 to estimate spring-flow/river baseflow from piezometric elevations. Approximately 124.7 km² of the basin is upstream of San Marcos Springs, formerly known as "Aquarena Springs," and another 121.9 km² comes from tributaries that enter the stream between San Marcos Springs and the Blanco River confluence, most of which comes from Purgatory Creek that drains the southern and western portions of San Marcos and adjacent areas. The changing of gaging station location necessitates consideration of where discharge measurements/values are based when analyzing the discharge record for the "San Marcos River at San Marcos." The area of former station no. 08170000 was listed by the USGS as 233.4 km², whereas station no. 08170500 has a drainage area of 129.7 km².

Virtually all of the non-flood flow in the river is supplied by San Marcos Springs, located on SWT property on the former Aquarena Springs commercial recreation site. These springs are the lowest natural piezometric outlet for the San Antonio section of the Edwards Aquifer (Hanson & Small 1995). In August 1956 (during the 1950s drought) the flow decreased to 1.3 m³/sec (46 ft³/sec), less than one third the 1957-1995 mean spring flow of 4.8 m³/sec (170 ft³/sec) (Table 1).

Near world-record rainfall intensities, provided by direct access to maritime tropical air from the Gulf of Mexico, and thin clay-rich soils
Figure 1. Upper San Marcos River Watershed (U.S. Soil Conservation Service 1978).
Table 1. Springflow and peak discharge for the San Marcos River (USGS 1956-1974; 1971-1999).

<table>
<thead>
<tr>
<th>Water Year</th>
<th>% Basin Control</th>
<th>Springflow mean ( m^3/sec ) (ft(^3)/sec)</th>
<th>Flood Stage ( m ) (ft.)</th>
<th>Flood Discharge ( m^3/sec ) (ft(^3)/sec) (Rank)</th>
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<td>(144)</td>
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<td>(274)</td>
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**** Springflow only data available; discharge based on well level.

a Discharge at Aquarena Drive new USGS gage no. 08170500
b Discharge estimate for gage no. 08170000 location based upon USGS slope area method (Dalrymple & Benson 1967).
make the Balcones Escarpment region of Texas known for its large flood discharges from seemingly small watersheds (Baker 1975). The San Marcos River is no exception. A hurricane-spawned flood in September 1921 produced a peak discharge of approximately 2750 m$^3$/sec (97,000 ft$^3$/sec), which is nearly 30% greater than the 1970 flood that provided the stimulus for the flood control project (Table 1). The peak flood discharge has exceeded 280 m$^3$/sec (10,000 ft$^3$/sec) at least 13 times in the last 30 years. There have been five precipitation events [1909, 1913 (two events), 1981, 1998] that have exceeded 254 mm/24 hours during the twentieth century (Slade 1986; Sands 1998; U.S. National Climate Data Center 2002).

**Urban Growth and Flood Control**

San Marcos and Southwest Texas State University have experienced considerable growth during the 1970-1995 period. Virtually all of this growth has occurred downstream of the USMWFCD dams. In a comparison of landuse using 1966 and 1989 air photos, Pulich et al. (1994) calculated more than a doubling of urban landuse, from 10.2% to 23.0%, along the uppermost 18.4 km of the San Marcos River from San Marcos Springs to Martindale. The City of San Marcos has implemented a series of grading ordinances that are intended to reduce runoff and sediment production from urbanized land both during and after construction. City regulations require adherence to US SCS guidelines as stated in *Erosion and Sediment Control Guidelines for Developing Areas in Texas* (U.S. Soil Conservation Service 1976). Besides these SCS rules, the city has designated a special "San Marcos River Corridor," which is defined as the area within 60 to 300 m of the center of the river, depending on drainage and terrain (City of San Marcos 1995). Even though the main SWT campus is entirely within the city limits, because it is a state institution, it is not subject to the city grading ordinances. This issue has particularly become apparent with the onset of construction for the new Lyndon B. Johnson Student Center and associated parking facilities that began in the spring of 1995. A large delta now occupies the confluence of Sessoms Creek and the San Marcos River; cobbles from the construction site are found as far as 60 meters below the confluence.

Until the October 1998 flood, there had been only one flow greater than 570 m$^3$/sec (20,000 ft$^3$/sec) since 1982 (Table 1). This absence of flooding correlates to the 1981-1991 construction of the headwaters flood control dams that decreased the unregulated watershed area to less
than one fourth its previous value. This flooding hiatus also correlates to an absence of flood producing storm events for nearby basins in the size range of the upper San Marcos River. For the Comal River drainage at New Braunfels, with a 337 km$^2$ basin, the largest flood between 1983 and 1998 was only 10.9% of the largest event since 1957 with a discharge of 1720 m$^3$/sec (60,800 ft$^3$/sec) in May 1972. The largest flood between 1983 and 1998 for the Blanco River at Wimberley, Texas, with a 921 km$^2$ drainage, was only 46% of the 30 year storm of record with 2730 m$^3$/sec (96,400 ft$^3$/sec) in May, 1958 (USGS 1999).

**October 1998 Flood**

The October 1998 flood was among the largest flood events in the history of the region (EARDC 1999; LCRA 1999; US NRCS 1999; USGS 1999). The official 401 mm (15.78 in) recorded on October 17, 1998 at the "San Marcos, Texas" weather station was the greatest 24-hr total recorded since records began in 1901 (Sands 1998), but the fifth event to equal or exceed the "official" 254 mm 100-year 24-hour total designated for this region by U.S. Weather Service Technical Paper 40 (Hershfield 1961; Baker 1975). The headwaters of the upper San Marcos River received 24 hour totals in the 400 to 500 mm range with the greatest amounts over the southern portions of the upper San Marcos basin that are drained by Purgatory Creek (LCRA 1999; US NRCS 1999). Runoff produced exceeded the design standard project flood of the Upper San Marcos River Project but did not exceed the maximum probable flood spillway capacities of the project flood control dams. Thus, whereas there was considerable "spill" from the event, the flow downstream of the flood control structures was considerably less than it would have been without the project dams.

Even with the flood control project, the storm generated impressive peak discharges. Runoff and maximum discharge on tributaries upstream of the Freeman Ranch dam showed peak runoff between 46 (1.8 in) and 86 (3.4 in) mm/hr and that peak inflow into the dam was 1870 m$^3$/sec (66,000 ft$^3$/sec) (Table 2). Maximum "spill" from Freeman Ranch dam was 331 m$^3$/sec (11,700 ft$^3$/sec), less than 20% of the maximum inflow. Farther downstream, the calculated inflow (Table 3) into Spring Lake was 420 m$^3$/sec (15,000 ft$^3$/sec) and the peak inflow of Purgatory Creek into the San Marcos River was 280 m$^3$/sec (10,000 ft$^3$/sec). Downstream of Spring Lake, but upstream of the confluence with Purgatory Creek, the USGS employing similar slope-area methods
Table 2. October 1998 peak runoff and discharge calculated for upstream tributaries of the Freeman Ranch Dam on the SWT Freeman Ranch employing the slope-area method (Dalrymple & Bensen 1967).

<table>
<thead>
<tr>
<th>Basin</th>
<th>Basin Area (ha)</th>
<th>Peak Discharge m³/sec &amp; mm/hr (ft³/sec &amp; in/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sink Creek</td>
<td>4,863 (48.6 km²)</td>
<td>1040 &amp; 79 (36,700 &amp; 3.1)</td>
</tr>
<tr>
<td>(Main Channel)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub-Basin B</td>
<td>76</td>
<td>9.8 &amp; 46 (345 &amp; 1.8)</td>
</tr>
<tr>
<td>Sub-Basin C</td>
<td>220</td>
<td>39.6 &amp; 53 (1400 &amp; 2.1)</td>
</tr>
<tr>
<td>Sub-Basin D</td>
<td>1,542</td>
<td>362 &amp; 86 (12,800 &amp; 3.4)</td>
</tr>
<tr>
<td>Sub-Basin E</td>
<td>144</td>
<td>22.7 &amp; 56 (800 &amp; 2.2)</td>
</tr>
<tr>
<td>Freeman Dam</td>
<td>8,692 (86.9 km²)</td>
<td>est. 1870 (66,000)</td>
</tr>
<tr>
<td>Freeman Dam Spill</td>
<td></td>
<td>331</td>
</tr>
</tbody>
</table>

Table 3. Calculation of Peak Discharge for October 1998 storm corrected to the location of USGS Gage 08170000 (downstream of I-35 bridge) (This study).

<table>
<thead>
<tr>
<th>Location</th>
<th>Discharge m³/sec (ft³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow to Spring Lake from Sink Creek (124 km²)</td>
<td>420 (15,000)</td>
</tr>
<tr>
<td>USGS Hopkins St. Estimate (155 km²)</td>
<td>610 (21,500)</td>
</tr>
<tr>
<td>Purgatory Creek inflow (78 km²)</td>
<td>280 (10,000)</td>
</tr>
<tr>
<td>Unregulated RO 31 km²</td>
<td>400 (14,000)</td>
</tr>
<tr>
<td>Estimated Peak</td>
<td>1270 (45,000)</td>
</tr>
</tbody>
</table>

calculated a peak discharge of 610 m³/sec (21,500 ft³/sec) at the Hopkins Street bridge (USGS 1999). When peak runoff coefficients are applied to other downstream areas below the flood control dams, plus the observed peak flows, an estimated value of 1270 m³/sec (45,000 ft³/sec)
was obtained for the peak discharge of the event as measured at the location of the former USGS gage no. 08170000 just east of the I-35 bridge (Table 3). If peak runoff values of 51 to 76 mm (2-3 in)/hr such as those measured upstream of the Freeman Ranch dam are applied to the whole basin, the peak discharge at the I-35 location would have been between 3370 and 4110 m$^3$/sec (119,000 and 145,000 ft$^3$/sec) had there been no flood control project. Rather than being the fourth largest event on the San Marcos River at San Marcos, the event would have exceeded the record 1921 event by a considerable margin (Table 1). The record discharges of the event are verified by the period of record/or near record period of record discharges measured on nearby streams with less or no flood control facilities such as on the Blanco at Wimberley and the Comal and Guadalupe Rivers at New Braunfels (Table 4) (USGS 1999; USNRCS 1999).

**Changes in the River**

Until the October 1998 event, the largest flood since completion of the first, and largest, flood control dam in 1983 was 38% of the 1970 event (Table 1). Between 1983 and 1998 flood damage along the river had been mostly limited to debris clean-up and gravel trail repair in areas immediately adjacent to the river. As discussed above, the flood control project dramatically reduced the flood magnitude of the 1998 event. West of Hopkins Street, damage from the flood was mostly restricted to structures at Aquarena Center, the first floor of the University Apartments on Aquarena Drive, and parks immediately along the river. Between Hopkins Street and I-35, more than 51 ha of residential and commercial areas were inundated and produced an estimated $12,100,000 in property damages (Adamietz 1999; US NRCS 1999).

Since 1990, the San Marcos River has been closely monitored by both the Texas Parks and Wildlife Department (TPWD) and the Parks and Recreation Department of the City of San Marcos. The TPWD studies supported the critical habitat monitoring for the stream's endangered species. The City of San Marcos studies, under the title of the "River Stewardship Project," have supported the development of a management plan for the river as a part of the Parks and Recreation Department master plan and as a part of the monitoring and management of this aesthetic and tourism resource for the city.

A major problem verified by these studies and observed by the public has been the increase in exotic river vegetation, particularly *Hydrilla*
Table 4. Peak discharges for the October 1998 storm observed at other gages on the Guadalupe River system as compared to earlier events (USGS 1956-1974; 1971-1999; 1999).

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Stage m (ft)</th>
<th>m³/sec (ft³/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1998</td>
<td>San Marcos at San Marcos</td>
<td>est. 8.7</td>
<td>1300 (45,000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(28.5)</td>
<td></td>
</tr>
<tr>
<td>1921</td>
<td>San Marcos at San Marcos</td>
<td>11.8</td>
<td>2700</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(38.6)</td>
<td>97,000</td>
</tr>
<tr>
<td>1998</td>
<td>Blanco at Wimberley</td>
<td>—</td>
<td>2500/3300*</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(88,500/116,000)</td>
</tr>
<tr>
<td>1929</td>
<td>Blanco at Wimberley</td>
<td>—</td>
<td>3200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(113,000)</td>
</tr>
<tr>
<td>1998</td>
<td>Blanco at Kyle</td>
<td>—</td>
<td>3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(105,000)</td>
</tr>
<tr>
<td>1929</td>
<td>Blanco at Kyle</td>
<td>—</td>
<td>3900</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(139,000)</td>
</tr>
<tr>
<td>1998</td>
<td>San Marcos at Luling</td>
<td>12.7</td>
<td>5800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(41.8)</td>
<td>(206,000)</td>
</tr>
<tr>
<td>1869</td>
<td>San Marcos at Luling</td>
<td>12.3</td>
<td>&gt; 2800</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(40.4)</td>
<td>(&gt; 100,000)</td>
</tr>
<tr>
<td>1998</td>
<td>Guadalupe at Gonzales</td>
<td>15.4</td>
<td>9600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(50.4)</td>
<td>(340,000)</td>
</tr>
<tr>
<td>1929</td>
<td>Guadalupe at Gonzales</td>
<td>15.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(49.3)</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Guadalupe at New Braunfels</td>
<td>11.7</td>
<td>6300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(38.5)</td>
<td>(222,000)</td>
</tr>
<tr>
<td>1913</td>
<td>Guadalupe at New Braunfels</td>
<td>12.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(39.5)</td>
<td></td>
</tr>
<tr>
<td>1869</td>
<td>Guadalupe at New Braunfels</td>
<td>12.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(39.5)</td>
<td></td>
</tr>
<tr>
<td>1998</td>
<td>Guadalupe at Victoria</td>
<td>10.3</td>
<td>13,200</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(33.8)</td>
<td>(466,000)</td>
</tr>
<tr>
<td>1936</td>
<td>Guadalupe at Victoria</td>
<td>9.5</td>
<td>5100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(31.1)</td>
<td>(179,000)</td>
</tr>
</tbody>
</table>

* USGS Flood peaks data base gives lower value than USGS 1999 report.

verticillata (hydrilla), Potamogeton illinoiesnsis (pondweed) and Colacasia escuelenta (elephant ear) (Lemke 1989; Staton 1992; Angerstein & Lemke 1994). In an analysis of this problem, Spain (1994) concluded that any program to control these exotics, including mechanical removal, biologic controls or herbicides, would be either expensive, controversial or illegal.
Another change observed by the public and verified by quantitative measurement has been sedimentation of the channel. Between 1990 and 1995, the City conducted annual sedimentation measurements at sites between University Drive and Hopkins Street. Employing a 0.63 cm diameter rod-penetrometer, sediment depth to the closest 0.1 m was measured every 3 meters across the channel at cross-sections every 25 meters in SWT Sewell Park and every 50 meters farther downstream. Between the scouring floods December 1991-January 1992 and 1995, there was an average channel deposition of 0.50 meters or 13,000 m$^3$ in the 800 meter reach of the stream immediately downstream from Spring Lake (Wood & Gilmer 1996).

**ANALYSIS OF HEADWATER CHANGES**

A hypothesis of this study is that the decrease in drainage area has reduced the number and maximum energy of stream erosional events. Furthermore, continued construction in the headwaters area downstream of the flood control dams has increased sediment input introduced into the river. Employing the slope-area method (Dalyrimple & Bentson 1967) for calculating bankfull discharge from channel geometry, the bankfull discharge in Sewell Park, immediately downstream of Spring Lake, is 33 m$^3$/sec (1150 ft$^3$/sec). Because of the changes in the location and instrumentation of gage number 0817000, it is difficult to determine the number of times that this discharge has been exceeded since the completion of the upstream dams. According to the formulas developed by Slade et al. (1995) for calculating peak discharge for a given recurrence interval ($Q_2 = 252A^{0.721}(SF)^{0.326}$ where $A =$ area in m$^2$ and SF = shape factor) with the tributary area of this segment reduced from 77.0 to 15.6 km$^2$, the bankfull discharge for the two-year event comes out to 35 m$^3$/sec (1240 ft$^3$/sec) or approximately bankfull discharge. As shown in Table 1, only the October 1998 event exceeded bankfull discharge since the December 1991 flood.

In contrast, prior to closure of the dams, bankfull discharge was exceeded in over 82% (23/28) of the years with a mean annual flood of 510 m$^3$/sec (18,000 ft$^3$/sec). This 510 m$^3$/sec (18,000 ft$^3$/sec) value has a recurrence interval of 3.6 years. If Slade et al.'s (1995) equations are used, the present-day 3.6 year flood or mean annual flood with the reduced basin comes out to 43 m$^3$/sec (1,500 ft$^3$/sec). The maximum drain release from the "Site #3 Sink Creek" dam, approximately two kilometers upstream of Spring Lake is 27 m$^3$/sec (936 ft$^3$/sec) but this discharge is only produced when the structure has received 254 mm
basin precipitation, the "100-year, 24-hr" event (US SCS 1978). Consequently, significant runoff below the flood control dams would be required to produce bankfull discharge in the main channel. Employing the TR 55 model, with a curve number of 75, between 38 and 54 mm/hr of precipitation is required to produce sufficient runoff to yield bankfull discharge (33 m$^3$/sec or 1150 ft$^3$/sec) downstream of Spring Lake (US SCS 1986). This precipitation rate has a recurrence interval of approximately two years, and thus, the decrease in bankfull events is at least partially due to a climatic perturbation that produced few high-intensity rainfalls between 1991 and 1998 (Hershfield 1961). Thus, both hydrologically (Slade et al. 1995) and rainfall frequency based models suggest that the 1991-1997 period of stream sedimentation was noted for its lack of large flood events.

Sedimentation results when sediment supply exceeds the ability of flood events to remove the sediment supply. A major source of the sediment introduced into the river is Sessoms Creek, with a basin area of 147 ha (363 acres) and which receives runoff from much of the SWT campus. Particularly noteworthy has been the recent construction on campus. An analysis of the sediment production from the site of the new student union and other facilities was undertaken with the Universal Soil Loss Equation (USLE) (Dunne & Leopold 1978). These areas had a bare, disturbed surface area of 7.3 ha and produced an estimated sediment yield of 121 tonnes/ha/year in contrast to an estimated pre-construction value of 0.22 tonnes/ha/year. Based upon a density of 2.0 g/cm$^3$, the annual sediment production from the construction site would have a volume of 780 m$^3$ compared to 15 m$^3$ for the remaining 140 ha of the basin. This sediment production rate over the three years of construction that began in 1995 would produce an annual sedimentation in the channel of the San Marcos River of 16 cm/year in the upper 250 meters of the river or at least 48 cm since 1995. The failure of the 1998 flood event to scour this sediment suggests that the sediment volume from Sessoms Creek is greater than the ability of even a major flood of the San Marcos River to erode and transport in the concrete lined main channel and farther downstream.

A potentially beneficial impact of the flood control project is the enhanced recharge to the Edwards Aquifer that occurs behind the USMWRFCD dams. Water that would have flowed down the San Marcos River as quickflow is now infiltrated and contributes to the water that is withdrawn by wells or emerges from San Marcos Springs.
The actual amount of enhanced recharge is a function of the mean annual runoff estimate. Interpolation between the 51 and 127 mm runoff lines on the runoff map produced by the USGS in 1970 produces an estimated 76 mm runoff for the region (USGS 1970). If runoff is calculated from the nearby gaged discharge/drainage basin area relationships, the regional runoff is approximately 127 mm (USGS 1921; 1956-1999). Lastly, if the regional annual runoff equation \( Q_{\text{ann}} = 10^{0.211} A^{0.846} \) developed by Lanning-Rush (2000) is employed, the 217 km\(^2\) above the dams have an estimated 287 mm runoff. If one uses the value of 127 mm runoff calculated from the adjacent basins, the mean annual runoff from the controlled 217 km\(^2\) regulated portion of the upper San Marcos basin is 27 million m\(^3\) (22,000 acre feet) /year. Other than aquifer seepage, the only natural outlet for this water is San Marcos Springs. If all of this enhanced recharge were to become springflow, it would increase the average baseflow of the river by 0.8 m\(^3\)/sec (30 ft\(^3\)/sec) or about 18%. Unfortunately, this recharge is dependent upon precipitation and this enhanced flow could not be expected during drought times when little surface runoff is produced. Looking at this enhanced recharge in terms of water supply, this additional water, based upon a value of $0.37 to $1.10/ m\(^3\) ($100 to $300/acre foot), is worth between $2.2 and 6.6 million per year. Presently, Texas law does not grant ownership to the party responsible for enhanced recharge, but the volatile status of Texas water law forced upon a reluctant state by increasing demand for water and periodic droughts will probably clarify the ownership of enhanced recharge (Kaiser 1986; Votteler 1998). Once this issue is resolved, the increased groundwater would become a resource for future water demand for San Marcos or could generate revenues.

MANAGEMENT OPTIONS

The altered hydraulic regimen of the San Marcos River brought about by the upstream flood control project can be accepted and adjusted to, or can be modified. Already the City and SWT have implemented a hydrilla "mowing" program to reduce vegetation clogging (Anonymous 1994). Other than accepting the sedimentation, a channel dredging program has been proposed and could be implemented. Dredging would raise legal concerns over the “taking” of endangered species, and consequently, other options need to be considered to shift the sediment supply/stream energy relationship. A different stream regime with some combination of increased total stream energy or a reduction of sediment supply is necessary to reverse the persistent sedimentation. Dam design
and operation could be modified to increase the amount of flow passed through the flood control dams on Sink Creek. On the other side of the equation, the amount of sediment entering the river could be reduced by enhanced efforts to reduce erosion and or implementation of a series of sediment check dams immediately upstream of where high sediment load tributaries enter the San Marcos River. The failure of the 1998 storm to produce a net scour of sediment deposited since 1991 suggests that with the present stabilized channel, the only means to reduce/reverse the sedimentation problems is to reduce sediment yield from the contributing watersheds.

An unresolved issue is the near autonomous status of SWT in terms of its actions affecting the river. University land constitutes 192 of the 940 ha of the drainage of Sessoms Creek, which includes the potential to cause considerable changes or damage to the river such as the leaky gasoline storage tank incident of 1994 proved (Dreckman 1994). City, county and even some state agencies cannot force SWT to modify its actions to protect the river because it is a state entity. This presents a fundamental problem for management in that such a significant landuser is immune from rules that are designed to protect such a valuable resource. With implementation of the next set of federal Water Quality Act (1987) rules in 2003, SWT will formally be required to treat its runoff from all new developments and be required to implement sediment control measures from all construction sites larger than 0.4 ha (1 acre) (U.S. Environmental Protection Agency 2000). Perhaps, enforcement of these rules on the SWT campus and elsewhere in the watershed of the upper San Marcos River watershed will significantly reduce the hydrologically overwhelming sediment load presently introduced into the river.

**DISCUSSION**

The recent changes in the San Marcos River illustrate a number of principles in environmental management. Hydrologically, the dams have reduced the magnitude and frequency of scouring flood events. Landuse changes downstream of the flood control dams have increased sediment yield so that the channel has adjusted through deposition. The reduction in peak flood energy has also led to an increase in exotic vegetation. These changes mimic those observed in the Grand Canyon of the Colorado following the closure of Glen Canyon Dam (Graf 1985; Carothers & Brown 1991). The trunk stream is unable to remove the sediment that is deposited at the mouths of the tributaries and there is
insufficient energy to flush out undesirable vegetation. Perhaps, a program as dramatic as the recent peak flood simulation in the Grand Canyon would be required (Webb et al. 1999). Public authorities would be reluctant to create or increase a flood that would further endanger lives and increase property damage for some uncertain benefit to the river. Sediment control through expanded implementation of the Water Quality Act (1987) will help with the sediment problem but other measures, perhaps more costly or controversial, will be required to deal with the increase in exotic vegetation. The recent changes in the San Marcos River brought about by the upstream flood control project illustrate the hydrologic and ecologic principle that reducing flood discharges establishes an entirely new stream regime that is often associated with a new set of management problems.

ACKNOWLEDGMENTS

We would like to thank Jeff Wilson, Karim Aziz and Andy Skadberg for helping with the maps and data analysis for this report. Melanie Howard, the San Marcos River steward, provided data for this report. John Dudik, Ryan Kainer and Barry Kolarik, past and present SWT students, assisted with the fieldwork and data analysis.

LITERATURE CITED


U.S. Geological Survey. 1999. Floods in the Guadalupe and San Antonio River Texas,

RAE at re02@swt.edu
The ghost-faced bat (Mormoops megalophylla) is broadly distributed in the tropics of southwestern North America and a portion of northern South America. The North American range of this species includes the southern three-fourths of Baja California, mainland Mexico and northern Central America (Hall 1981; Cameron 1993). The northern distributional limit of M. megalophylla reaches southeastern Arizona and southern Texas near the Rio Grande (Cameron 1993).

In Trans-Pecos Texas, M. megalophylla has been recorded in only Brewster, Presidio and Culberson counties (Davis & Schmidly 1994). This new record from Jeff Davis County fills a gap in distribution between northern, extralimital records for the ghost-faced bat at Elephant Mountain in Brewster County (Bradley et al. 1999) and the Apache Mountains in Culberson County (Stangl et al. 1994), which are, respectively, 72 km SE and NW of the new record.

On 4 October 2000, two female ghost-faced bats (one non-lactating adult and one sub-adult) were captured in a 12 m, four-tiered mist net set across Limpia Creek at Davis Mountains State Park (DMSP) (elevation 1522 m, UTM coordinates: 13 603632E 3385791N). The first ghost-faced bat came in at 2122 hr, which was about 90 minutes after sunset, and the second came in at 2220 hr. The sky was clear, the temperature was 24°C, and the wind blew about 15 km/h during the times of capture. Eighty-four other bats (one Myotis velifer, 22 Nyctinomops macrotis and 61 Tadarida brasiliensis) flew into this single net between 2010 hr and 2300 hr.

The net was located over an open, slow moving, ephemeral pool that was 13 m wide by about 55 m long. The site of capture was in a broad, sloping canyon with a mosaic of oak-juniper and montane grassland that had been invaded by shrubs.
Yancey (1997) recorded *M. megalophylla* as the second most common bat at Big Bend Ranch State Park, which indicates a healthy population of this species 83 km south of the Davis Mountains. Furthermore, this record for the Davis Mountains is the third northern, extralimital record for the species in less than 20 years. These data support the idea that the ghost-faced bat is undergoing an expansion of range northward (Bradley et al. 1999). However, the lack of breeding individuals among these records contradicts this evidence. Alternatively, these records might be of individuals searching for food or water outside the normal range for the species during times of drought.

Additionally, this net site was about 250 m upstream from a locality where Jones et al. (1999) recorded the first capture of the western yellow bat, *Lasiurus xanthinus*, from the Davis Mountains. In contrast to this *Mormoops* locality, that site was fed by a permanent spring and supported mature, riparian woodland that was nearly closed canopied. These records are too few to draw many comparisons between the two species at the two sites. However, the captured individuals occurred in habitats with potential roost sites respective to each species.

The skins, skulls, post-cranial skeletons and frozen tissues (TK 92913, 92914) of these two specimens are deposited in the Collection of Recent Mammals in the Natural Science Research Laboratory, the Museum of Texas Tech University. The materials are cataloged under the numbers TTU 82461 and TTU 82462.

**ACKNOWLEDGMENTS**

These specimens were obtained from DMSP in accordance with scientific collecting permit SPR-0790-189, which was issued by the Texas Parks and Wildlife Department. Kelly Bryan, Linda Hedges and John Holland facilitated the overall project at DMSP. Ernest W. Valdez helped prepare the specimens, and Linda Hedges and Kelly Bryan helped characterize the habitat. This project was in accordance with a partnership between the Texas Parks and Wildlife Department, the Nature Conservancy of Texas, and Texas Tech University.

**LITERATURE CITED**


CJ at: cjones@packrat.musm.ttu.edu
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THE EFFECT OF THE NUMBER OF SENSORS ON
THE MAGNITUDE OF THE MAXIMUM OBSERVED OZONE

D. Dorsett and N. Miserendino

Department of Information Systems
Baylor University, Waco, Texas 76798

Abstract.—For environmental studies of pollution, the number of sensors involved can vary considerably. This paper investigates the effect when two regions with the same level of ozone but differing number of sensors are measured. The method indicated in the analysis allows for the adjustment of measurement levels for different number of sensors.

It seems reasonable that the larger a geographical region the greater the chance that somewhere within that region one will find a high concentration of ozone. Similarly, a greater number of observation stations (sensors) within the region should also increase the chance that one out of the set of sensors will observe a high ozone concentration.

The analysis in this paper is motivated by comments by a statistician and meteorologist at the Texas Natural Resources Conservation Commission and by the work of David P. Chock, Research Laboratory, Ford Motor Company, Dearborn, Michigan and his research associates.

The principal purpose of this paper is to define a relationship between the expected maximum observed daily ozone (O₃) and the number of sensors and the number of observations per sensor in the region. The analysis is relatively simple but hopefully sufficiently useful and applicable when extended to more realistic and operational situations.

Also, if one is convinced that regulations for improving air quality are better applied and understood when standards are written with respect to mean concentration and the variability of concentrations and not with respect to maximum observed concentrations, then one can use a method indicated by the analysis formulated in this paper to relate expected high level ozone when various number of sensors are being used to monitor air quality to the desired mean level of ozone allowed. The method allows one to adjust the estimates from two regions having the same mean level of ozone, yet different numbers of sensors, which are judged regions with unequal concentration with respect to observed maximum ozone. Conversely, areas with different observed levels of ozone can be judged the same with respect to maximum ozone levels when the number of sensors in each region are different.
Currently, two regions with the same mean level of ozone, and same standard deviation of ozone may not be judged equal due solely to the fact that there are different numbers of sensors in each of the two regions. The greater number of sensors in a region increases the chance for a greater number of exceedances in that region even though the distribution of concentrations of the two regions are the same.

The analysis formulated in this paper is based on the fundamental concepts of order statistics (Sarban & Greenbing 1962; Gibbons 1971; Hogg & Craig 1978).

**Mathematical Preliminaries**

Let $X_1, X_2, ..., X_n$ denote a random sample from a pdf $f_X(x)$; the cumulative pdf is denoted by $F_X(x) = \Pr[X \leq x]$, and $X_{(1)} < X_{(2)} < \ldots < X_{(n)}$ denote the sample ordered with respect to magnitude. For convenience of notation, let $Y_i = X_{(i)}, i = 1, 2 ..., n$. Then $Y_n = \max[X_i]$. The pdf of $Y_n$ is

$$f_{Y}(y_n) = n[F_X(y_n)]^{n-1}f_X(y_n)$$

(1)

and if $f_X(x)$ is known, then $E[Y_n]$ and $V[Y_n]$ (the mean and variance) could be computed. If $f_X(x)$ is not known, approximate techniques are available.

For purposes here a normality assumption is made for $f_X(x)$ to obtain illustrative numerical values (Gibbons 1971). The asymptotic formulas are as follows:

$$E [y_n] = F_X^{-1} \left[ \frac{n}{n + 1} \right]$$

(2)

$$V[y_n] = \frac{n}{(n + 1)^2(n + 2)} \left( f_X \left[ F_X^{-1} \left( \frac{n}{n + 1} \right) \right] \right)^2$$

(3)

Suppose that $Z_i = (X_i - \mu_X) / \sigma_X \sim N(0,1), i = 1, 2, ..., n$, then

$$E [Z_{max}] = F_Z^{-1} \left( \frac{n}{n + 1} \right)$$

(4)
\[ V[Z_{\text{max}}] = \frac{n}{(n+1)^2(n+2)} \left\{ f_z \left[ F_z^{-1}\left( \frac{n}{n+1} \right) \right] \right\}^{-2} \]  

(5)

where

\[ f_z = \frac{1}{\sqrt{2\pi}} \exp\left( \frac{1}{2} z^2 \right), \]

\[ F_z = \int_{-\infty}^{z} f_z(z)dz, \]

and

\[ E[X_{\text{max}}] = \mu_X + \sigma_X E[Z_{\text{max}}], \]  

(6)

\[ V[X_{\text{max}}] = \sigma_X^2 V[Z_{\text{max}}]. \]  

(7)

In Table 1, the values of \( E[Z_{\text{max}}] \) and \( V[Z_{\text{max}}] \) are tabulated when \( Z \sim N(0,1) \). The entries in Table 1 are used later to calculate \( E[X_{\text{max}}] \) and \( V[X_{\text{max}}] \) when \( X_t \sim N(\mu_X, \sigma_X^2) \). These quantities appear in Table 2.

Thus, suppose there are eleven sensors and one observation per sensor \((n=11)\), one would expect \( E[Z_{\text{max}}] = 1.38 \), or 1.38 sigma’s above the mean \( E[Z] = 0 \). The variance of \( Z_{\text{max}} \) is 0.250, or the standard deviation of \( Z_{\text{max}} \) is \( SD[Z_{\text{max}}] = \sqrt{V[Z_{\text{max}}]} = 0.05 \).

A 2-sigma interval estimate for \( Z_{\text{max}} \) is

\[ 1.38 - 2(0.05) \leq Z_{\text{max}} \leq 1.38 + 2(0.05), \]

or

\[ 1.28 \leq Z_{\text{max}} \leq 1.48. \]

And finally, if \( X_i \sim N(0.060, (0.05)^2) \), then

\[ E[X_{\text{max}}] = 0.060 + 1.38(0.05) \]

\[ V[X_{\text{max}}] = (0.05)^2(0.25) \]

\[ = 0.000625, \]

\[ SD[X_{\text{max}}] = 0.025. \]

A two-sigma interval estimate for \( X_{\text{max}} \) is

\[ 0.079 \leq X_{\text{max}} \leq 0.179, \]

or, in ppb,

\[ 79 \text{ ppb} \leq X_{\text{max}} \leq 179 \text{ ppb}. \]
Table 1. The Mean, $E[Z_n]$, and Variance, $V[Z_n]$, of the Max $Z_i$, $i=1,2,...,n$, when $Z \sim N(0,1)$ versus the number of observations ($n$).

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The Main Results

Table 3 lists several locations of interest, the number of sensors at each location, and the approximate sizes of the region defining the location. Figure 1 gives an indication of how ozone varies diurnally by graphing the amounts of ozone by hour of the day. This shows that maximal ozone occurs between 1300 and 1800 (Cleveland et al. 1976). Hence one can expect four observations per station to be especially relevant for the analysis here.

Using Table 1 and equations (6) and (7), Table 2 gives the $E[X_{max}]$ for $n=1,...,44$ and for

$$\mu_x=0.06, \; 0.08 \text{ and } 0.10,$$

$$=60, \; 80, \text{ and } 100 \text{ ppb}, \text{ and}$$

$$\sigma_x=0.02, \; 0.04 \text{ and } 0.06,$$

$$=20, \; 40, \text{ and } 100 \text{ ppb}.$$
Table 2. \( E[X_{\text{max}}] \) for various values of \( \mu_X \) and \( \sigma_X \) versus number of observations.

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</table>

Table 3. Locations, number of sensors and sizes.

<table>
<thead>
<tr>
<th>Location</th>
<th>1990-91</th>
<th>1992-93</th>
<th>Size of Region (sq. miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston</td>
<td>11</td>
<td>11</td>
<td>1777</td>
</tr>
<tr>
<td>Dallas/FW</td>
<td>5</td>
<td>7</td>
<td>1808</td>
</tr>
<tr>
<td>Austin</td>
<td>2</td>
<td>2</td>
<td>1000</td>
</tr>
<tr>
<td>San Antonio</td>
<td>2</td>
<td>2</td>
<td>1247</td>
</tr>
<tr>
<td>El Paso</td>
<td>3</td>
<td>4</td>
<td>526</td>
</tr>
</tbody>
</table>
For example, Houston has eleven sensors with four observations of interest per day per sensor, giving a total of 44 observations each day to order with respect to magnitude. The expected maximum ozone reading can be read from Table 2 for the various situations. Also, the variation in the distribution of the maximum value due to different numbers of observations are illustrated in Figures 2 and 3.

Currently, a day in which $X_{\text{max}} > 120$ ppb is declared an exceedance day or ozone episode. The probability of observing and exceedance day is also a function of the number of observations. Using this as the cutoff, and the distributions in Table 2, Table 4 gives the $P[X_{\text{max}} > 120]$ ppb. The effect of increasing the number of observations from which the maximum is determined is clearly seen under varying distributions.

**Some Suggested Strategies**

There are several reasonable ways to write air quality (ozone) regulations, some based on the average of several hourly ozone measurements,

$$\bar{x} = \frac{\sum_{i=1}^{s} \sum_{j=1}^{n_i} x_{ij}}{\sum_{i=1}^{s} n_i},$$

where $s$ is the number of sites (sensors) in the region and $n_i$ is the total number of observations per site. Usually the $n_i$ are constant for a region.
Thus, a strategy to define an ozone episode is:

If $X \geq \bar{x}_c$ for some critical value $\bar{x}_c$; that is, if a daily average (or a partial daily average) $X$ exceeds a pre-assigned amount $\bar{x}_c$, then that day is said to be an ozone exceedance day or an episode has occurred.
CONCLUDING REMARKS

Consider for example the locations Houston, Dallas/FW and El Paso. Houston has eleven sensors, Dallas/FW has seven and El Paso has four. Then let the average ozone be $\mu_x = 60$, $80$, and $100$ ppb, and the standard deviation $\sigma_x = 20$ ppb. The following values in Table 5 were obtained using Table 2.
Table 5. Expected Maximum ($\sigma_x$ ppb) = 20 ppb.

<table>
<thead>
<tr>
<th>Location</th>
<th>$\mu_x = 60$</th>
<th>$\mu_x = 80$</th>
<th>$\mu_x = 100$</th>
<th>$\sigma_{\text{max}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston (n=11)</td>
<td>115</td>
<td>135</td>
<td>155</td>
<td>11.6</td>
</tr>
<tr>
<td>D/FW (n=7)</td>
<td>106</td>
<td>126</td>
<td>146</td>
<td>10.7</td>
</tr>
<tr>
<td>El Paso (n=4)</td>
<td>93</td>
<td>113</td>
<td>136</td>
<td>10.0</td>
</tr>
</tbody>
</table>

For example, if $\mu_x = 60$ and $\sigma_x = 20$ ppb and one assumes that the pdf of observations is normal, then

$$\Pr[20 < X < 100] = 0.95 \text{ for all three locations, but}$$

$$\Pr[X_{\text{max}} > 120 | \text{Houston}] = 0.337,$$

$$\Pr[X_{\text{max}} > 120 | \text{D/FW}] = 0.096, \text{ and}$$

$$\Pr[X_{\text{max}} > 120 | \text{El Paso}] = 0.004.$$  

The probabilities are approximations and the last three are not equal since the number of sensors at each location are not equal; even though the ozone distributions are the same for each location.

The average of ozone measurements for each location will be "close" to 60 ppb at each of the three locations, but the expected maximum and the probabilities of an ozone episode varies due solely to the unequal number of sensors at the different locations.

Conversely, consider two regions, one with eleven sensors (like Houston) and one with two sensors (like Austin) and suppose that $E[X] = 80$ ppb and $\sigma_x = 40$ at both Houston and Austin. Then if $X_{\text{max}} = 135$ at Houston and $X_{\text{max}} = 107$ at Austin, Houston is declared in exceedance and Austin is not, even though Austin's air quality is the same as that of Houston's. These results are from Table 2.

It is important to note that in this case, Houston would be in exceedance while Austin would not, yet both would be experiencing the same distribution of ozone in the sense that $E[X|\text{Houston}] = E[X|\text{Austin}] = 80$ ppb and $\sigma_x = 40$ ppb.

It is true that if the concentrations of ozone are bounded by the true largest value (which we denote by the parameter, $\hat{\theta}$), then the greater number of sensors will give a better estimate for the actual largest value, $\hat{\theta}$.

For example let the observations be distributed uniform on the interval $(0, \hat{\theta})$; that is, the pdf of $X$ is

$$f_X(x) = 1/\hat{\theta}, \quad 0 \leq x \leq \hat{\theta}.$$
Then the \( E[X_{\text{max}}] = \frac{n}{n + 1} \) \( \theta \).

Some exemplary values are given in Table 6.

A final example illustrates that if there exists an upper bound for ozone concentration, that there also exists difficulties with estimating and making decisions using observed maximum ozone. Differences in distribution of ozone can be overlooked. Let

\[
X_1 \sim f_1 = 2 - 2x_1, \quad 0 < X_1 < 1, \text{ and}
\]

\[
X_2 \sim f_2 = 2x_2, \quad 0 < X_2 < 1.
\]

The largest ozone concentration is represented by the value unity in the inequalities \( 0 < X_i < 1 \). Using the approximations which appear earlier in this paper,

\[
E[X_{\text{max}}|f_1] = \left[1 - \sqrt{\frac{n}{n+1}}\right],
\]

and

\[
E[X_{\text{max}}|f_2] = \left(\frac{n}{n+1}\right)^{\frac{1}{2}}.
\]

Further, if

\[
X_1 \sim f_1 = \frac{2}{\theta} - \frac{2}{\theta^2} x_1, \quad 0 < X_1 < \theta, \text{ and}
\]

\[
X_2 \sim f_2 = \frac{2}{\theta^2} x_2, \quad 0 < X_2 < \theta,
\]

then

\[
E[X_{\text{max}}|X_1] = \left[1 - \sqrt{\frac{1}{n+1}}\right],
\]

\[
E[X_{\text{max}}|f_1] = \left[1 - \sqrt{\frac{1}{n+1}}\right],
\]

\[
E[X_{\text{max}}|f_2] = \theta \left(\frac{n}{n+1}\right)^{\frac{1}{2}},
\]

where \( \theta \) is the maximum possible concentration of ozone. Table 7 gives a display of \( E[X_{\text{max}}] \) for this situation.
Table 6. $E[X_{\max}]$ versus the number of observations when the maximum concentration possible is $\hat{\theta} = 80$ ppb and $\hat{\theta} = 130$ ppb. ($E(x) = \hat{\theta}/2$ and $V(X) = \hat{\theta}^2/12$).

<table>
<thead>
<tr>
<th>n</th>
<th>$\hat{\theta}$</th>
<th>80</th>
<th>130</th>
<th>n</th>
<th>$\hat{\theta}$</th>
<th>80</th>
<th>130</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>53</td>
<td>87</td>
<td></td>
<td>4</td>
<td>64</td>
<td>104</td>
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<td>15</td>
<td>75</td>
<td>122</td>
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<td>73</td>
<td>118</td>
<td></td>
<td>22</td>
<td>76</td>
<td>124</td>
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</table>

Table 7. Maximum expected ozone when $X_1 \sim f_1$ and $X_2 \sim f_2$.

<table>
<thead>
<tr>
<th>n</th>
<th>$E[X_{\max}]$ when $\hat{\theta} = 130$ ppb</th>
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<tbody>
<tr>
<td></td>
<td>$f_1$</td>
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<tr>
<td>1</td>
<td>0.33$\hat{\theta}$</td>
</tr>
<tr>
<td>2</td>
<td>0.42$\hat{\theta}$</td>
</tr>
<tr>
<td>5</td>
<td>0.59$\hat{\theta}$</td>
</tr>
<tr>
<td>7</td>
<td>0.65$\hat{\theta}$</td>
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<tr>
<td>11</td>
<td>0.72$\hat{\theta}$</td>
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<td>22</td>
<td>0.79$\hat{\theta}$</td>
</tr>
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<td>44</td>
<td>0.85$\hat{\theta}$</td>
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</table>

The results in Table 7 give expected maximal observed concentrations for two district distribution of ozone with the same upper bound on the concentrations of ozone.

The purpose of this paper was to give examples that will clarify understanding the effect of different numbers of sensors in different regions on the magnitude of the largest hourly ozone observed in a single day.

ACKNOWLEDGMENTS

We wish to thank David P. Chock of Ford Motor Company for providing "A Statement of Ford Motor Company before the US EPA on the Ozone Design Value Study of the Clean Air Act Amendments of 1990" as well as a set of visuals entitled "A Monte Carlo Simulation of the Ozone Attainment Process."

LITERATURE CITED


DD at: Dovalee_Dorsett@baylor.edu
Abstract.—Based upon both historical records and recent collections, a total of 86 species of fish in 19 families are reported from Caddo Lake in northeast Texas. A large fraction of these are both native and essentially freshwater species; only four are introduced (Cyprinus carpio, Morone chrysops, M. saxatilis and Stizostedion vitreum) and only two migrate from estuaries (Alosa crysochloris and Anguilla rostrata). This diversity represents more than half of the native nonestuarine species known from Texas. Seventeen additional species which are expected to occur in Caddo Lake are also reported. The fish diversity of Caddo Lake is compared with other regions of North America.

The extraordinary diversity of Caddo Lake freshwater fishes is undoubtedly related to its unique habitat diversity and minimal human disturbance. Many Texas streams have had substantial anthropogenic changes (Anderson et al. 1995; Hubbs et al. 1997). Additionally, among Texas waters it is close to the center of North American freshwater fish diversity that is greatest in the southern Appalachian region, and which tends to decrease with distance from that focal center (Hocutt & Wiley 1986). Nevertheless, Caddo Lake is unique for Texas as a relatively undisturbed and biologically diverse ecosystem.

This study is based upon both historical records as well as recent collections. Voucher specimens are deposited with the holdings of the Texas Cooperative Wildlife Collection (TCWC) of Texas A&M University, the Texas Natural History Collection (TNHC) of the University of Texas at Austin, the University of Louisiana at Monroe (NLU), the Strecker Museum (SM) of Baylor University and the Oklahoma State University Collection (OSUS). However, many of the species reported in this study were collected only by the late Robert J. Kemp who was the resident biologist in Marshall with the Texas Game and Fish Commission for more than 20 years. Both the presence and identification of specimens of these species was earlier verified by the author. Unfortunately, these reference collections were discarded by later workers. Those species noted with an asterisk (*) are those which were collected by Robert J. Kemp.
Documented Species

Family Petromyzontidae

*Ichthyomyzon castaneus.*—The chestnut lamprey is a parasitic lamprey that is well known in the Austroriparian area.

Material examined.—TCWC 38701.

Family Polyodontidae

*Polyodon spathula.*—This species is considered a species of concern by Texas Parks and Wildlife. Paddlefish have declined recently as a result of dams that are barriers to their migration.

Family Lepisosteidae

*Lepisosteus osseus.*—The longnose gar is abundant throughout Texas and is a major predator on all fish and competitor to largemouth bass. Like all gars, it has limited gill capacity and often has to breathe atmosphere air. Like all gars, it has a ganoid scale armor that provides protection against most predators.

*Lepisosteus oculatus.*—The spotted gar is widely distributed in the Austroriporian. Like the longnose gar, it is a major fish predator and competitor with largemouth bass.

Material examined.—TCWC 31902.

*Lepisosteus platostomus.*—The shortnose gar is widely distributed in the Austroriparian. Like all gars, it is a major fish predator and a competitor with largemouth bass.

*Lepisosteus spatula.*—The alligator gar is the largest gar and widely distributed in east Texas. As a large predator fish it eats many fish.

Family Amiidae

*Amia calva.*—The bowfish is widely distributed in the Austroriparian. Like the gars, it is predacious on fish and competes with largemouth bass.

Material examined.—TCWC 50501.
Family Anguilidae

*Anguilla rostrata.*—The American eel is catadromous and breeds in the Sargassa Sea. Dams have precluded young eelers from repopulating Caddo Lake.

Family Clupeidae

*Alosa chrysochloris.*—Shipjack herring is an estuarine fish and dams in the lower Mississippi and Red rivers have precluded repopulation.

*Dorosoma cepedianum.*—Gizzard shad are abundant in most of Texas. It is often considered a troublesome fish as they can become so abundant that they dominate the food chain in reservoirs and reduce abundance of game fish. Adults are too large to be prey to most game fish.

*Material examined.*—TNHC 1910.

*Dorosoma petenense.*—Threadfin shad are southern in origin and often die during cold winters. The original specimens were collected in Guatemala’s Lake Peten. They compete with gizzard shad and never get too large to be eaten by game fish.

Family Cyprinidae

*Cyprinella lutrensis.*—The red shiner is native to most of Texas. It has been widely used as a bait fish and has been introduced into many areas and causes major problems in the Colorado River near Grand Canyon.

*Cyprinella venusta.*—The blacktail shiner is native to the eastern half of Texas. It formed a hybrid swarm with red shiners downstream from a gravel pit in the Guadalupe River. After that wash water was removed from the river the hybrid number diminished.

Family Catostomidae

*Cyprinus carpio.*—Common carp are now widespread in the United States. It was introduced into North America by the U.S. Fish Commission in the 1800’s as a food and game species. It was widely distributed in Texas by the first Game and Fish Commission. That effort was so successful and so harmful to the native game fishes that the first Commission was dissolved by the legislature after five years.
*Hybognathus hayi.*—The cypress minnow is abundant in the Austroriparian. Like all minnows and shiners it is an essential part of the food chain.

*Hybognathus nuchalis.*—The Mississippi silvery minnow is abundant in the Austroriparian.

*Luxilis chrysocephalus.*—The striped shiner is abundant in the Austroriparian.

*Lythurus fumeus.*—The ribbon shiner is abundant in the Austroriparian.

*Lythurus umbratilis.*—The redfin shiner is abundant in the Austroriparian.

*Notemigonus crysoleucas.*—The golden shiner is abundant in the eastern half of the United States. It is extensively used as a bait fish and scattered populations now occur in western states.

*Notropis amnis.*—The pallid shiner is widely distributed in the Austroriparian. It has a distensible ventral mouth and feeds on the lake bottom.

*Notropis atherinoides.*—The emerald shiner is widely distributed in the eastern United States. It is commonly abundant in lakes but not so in Texas reservoirs.

*Notropis atrocaudalis.*—The blackspot shiner is widely distributed in the Austroriparian and is common in east Texas clear creeks.

*Notropis blennius.*—The river shiner is widely distributed in Austroriparian rivers.

*Notropis chalybeus.*—The ironcolor shiner is scarce in Austroriparian creeks.

*Material examined.*—TNHC 1303.
*Notropis maculatus.*—The taillight shiner is scarce in Austroriparian creeks.

*Materiel examined.*—TCWC 319010.

*Notropis texanus.*—The weed shiner is abundant in Austroriparian creeks.

*Materiel examined.*—NLU 65871.

*Notropis volucellus.*—The mimic shiner is abundant in Austroriparian creeks.

*Materiel examined.*—TNHC 8132.

*Notropis hubbsi.*—The bluehead shiner is often found in cypress filled natural lakes. It has been collected in Texas only in Caddo Lake.

*Materiel examined.*—TNHC 3965.

*Opsopoeodus emiliae.*—The pugnose minnow is abundant in the Astroriparian. It has a distensible ventral mouth and commonly feeds on the button.

*Materiel examined.*—TNHC 1302.

*Pimephales vigilax.*—The bullhead minnow is abundant in the Austroriparian.

*Semotilus atromaculatus.*—The creek chub is abundant in eastern United States. It is a large piscivorous minnow that may compete with game fish.

Family Catostomidae

*Carpiodes carpio.*—The river carp sucker is like most suckers in having a ventral mouth and feeding on the lake bottom. It is abundant over most of Texas and often is very abundant in reservoirs.

*Erirnyzon oblongus.*—The creek chubsucker is abundant in streams in the eastern United States. It has a small population in the headwaters of the South Guadalupe River and once occurred in the Devils River before Amistad Reservoir was constructed.
*Erimyzon succetta.—The lake chubsucker is abundant in lakes in the eastern United States.

*Ictiobus bubalus.—The smallmouth buffalo is abundant in the eastern United States. Like all buffalo they may become excessively abundant in Texas reservoirs.

*Ictiobus cyprinellus.—The bigmouth buffalo is abundant in the eastern United States. Like all buffalo they may become excessively abundant in Texas reservoirs.

*Ictiobus niger.—The black buffalo is abundant in the eastern United States. Like all buffalo they may become excessively abundant in Texas reservoirs.

Minytrema melanops.—The spotted sucker is abundant in the Austro-riparian.

Material examined.—TNHC 1911.

Family Ictaluridae

*Ameiurus melas.—The black bullhead is abundant in the eastern United States. Like most bullheads, this species seldom gets large enough to be eaten by humans. Small black bullheads have pectoral and dorsal spines with a very painful toxin when penetrating skin.

*Ameiurus natalis.—The yellow bullhead is abundant in the eastern United States.

*Ictalurus furcatus.—The blue catfish is abundant in eastern United States. This catfish grows to large size and is often used for human food consumption.

*Ictalurus punctatus.—The channel catfish is abundant in eastern United States. This catfish is extensively used in aquaculture. It is more common in streams than the blue catfish.

Noturus gyrinus.—The tadpole madtom is abundant in the Austro-riparian. The common name of this small fish is derived from its ability to inflict painful stings.

Material examined.—TNHC 1305.
*Noturus nocturnus.*—The freckled madtom is abundant in the Austro-riparian. Like *Noturus gyrinus*, it can inflict painful stings.

*Pylodictis olivaris.*—This large catfish is common in eastern United States. It is commonly used by poachers.

Family Esocidae

*Esox americanus.*—The grass pickerel is abundant in eastern United States. This is a small pickerel and seldom used as a game fish.

*Material examined.*—TNHC 1490.

*Esox niger.*—The chain pickerel is common in eastern United States. This moderate sized pickerel is used as a game fish.

*Material examined.*—TNHC 1306.

Family Aphredoderidae

*Aphredoderus sayanus.*—The pirate perch is abundant in the Austroriparian. It’s anus migrates anteriorally during development so that it is located in its throat. It incubates its eggs in its gill pouch.

*Material examined.*—TNHC 1494.

Family Cyprinodontidae

*Fundulus chrysotus.*—The golden topminnow is abundant in the Austroriparian. Like all topminnows this species feeds on the surface and is a part of the food chain.

*Material examined.*—NLU 65864.

*Fundulus dispar.*—The starhead topminnow is abundant in the Austroriparian.

*Material examined.*—TNHC 936.

*Fundulus notatus.*—The blackstripe topminnow is in the Austroriparian.

*Material examined.*—TNHC 1308.
Fundulus olivaceous.—The blackspotted topminnow is similar to the black stripe topminnow but tends to be more common in headwaters.

*Material examined.*—TCWC 319009.

Family Poeciliidae

Gambusia affinis.—The western mosquito fish is abundant all over Texas. It is viviparous and produces living young. It has been extensively used by mosquito control agencies as they feed on mosquito larvae. Together with its near relative (G. holbrooki) they are found in all continents except Antarctica. Their use has been detrimental to many native fishes which are as good in controlling mosquito abundances.

*Material examined.*—TNHC 1307.

Family Atherinidae

Labidesthes sicculus. The brooksilverside is abundant in eastern United States streams. It can be very abundant in lakes and reservoirs in the absence of other silversides.

*Material examined.*—TNHC 1320.

Menidia beryllina.—The inland silverside is abundant in eastern United States estuaries and adjacent rivers. It is native to Caddo Lake. It has been introduced widely into Texas reservoirs where it flourishes. Its abundance is in part due to high reproduction rate. A female lays up to 1000 eggs daily comprising 6% of her biomass for four summer months. As the season progresses males become much less abundant as they are readily consumed by bass while in pursuit of females.

*Material examined.*—TNHC 1419.

Family Percichthyidae

*Morone chrysops.*—The white bass is native to eastern states. It is probably an exotic in Caddo Lake as they are known to be native in Texas only in the downstream reach of the Red River. It has been widely introduced into Texas reservoirs as a game fish.

Morone mississippiensis.—The yellow bass is abundant in the Austroriparian. It is not extensively used as a game fish as it is
relatively small.

*Material examined.—TNHC 1912.*

*Morone saxatilis.—* The striped bass is native to Atlantic estuaries. It has been widely introduced into Texas reservoirs as a game fish. Striped bass and white bass hybrids are also used as game fish.

Family Centrarchidae

*Elassoma zonatum.—* The banded pigmy sunfish is abundant in creek filled Austroriparian waters. It is vastly too small to be considered as a game fish.

*Material examined.—TNHC 1312.*

*Centrarchus macropterus.—* The flier is abundant in the Austroriparian. It is of moderate size and not extensively used by sport fishermen.

*Lepomis cyanellus.—* The green sunfish is abundant in the eastern United States. Its moderate size means moderate use as a game species.

*Material examined.—SM 1520.*

*Lepomis gulosus.—* The warmmouth is abundant in the eastern United States. Its moderate size leads to minimal use as a game fish. Like the green sunfish it has a relatively large mouth for a sunfish of its size.

*Material examined.—TNHC 1319.*

*Lepomis macrochirus.—* The bluegill is widely distributed in the eastern United States. Its relative large size makes it a sought after game fish. Atlantic coastal populations tend to be heavier than the Texas natives and are often considered a better game fish.

*Material examined.—TNHC 1318.*

*Lepomis marginatus.—* The dollar sunfish is widely distributed in the Austroriparian. It is too small to be used as a game fish.

*Material examined.—TNHC 1314.*

*Lepomis megalotis.—* The longear sunfish is abundant throughout the
eastern United States. It is too small to be used extensively as a game fish.

*Material examined.*—TNHC 1496.

*Lepomis microlophus.*—The redbreast sunfish is common in the Austro-riparian. It is relatively large for a sunfish and is extensively used as a game fish.

*Material examined.*—TNHC 1313.

*Lepomis punctatus.*—The spotted sunfish is abundant in the Austro-riparian. It is relatively small and little used as a game fish.

*Material examined.*—TNHC 1315.

*Lepomis symmetricus.*—The bantam sunfish is abundant in the Austro-riparian. It is much too small to be used as a game fish.

*Material examined.*—TNHC 1316.

*Micropterus punctulatus.*—The spotted bass is abundant in the Austro-riparian. It is extensively used as a game fish.

*Micropterus salmoides.*—The largemouth bass is widely abundant in the eastern United States. It is the prime freshwater game fish in the United States and subsequently introduced into temperate waters worldwide. The Florida subspecies is even longer and more sought after as a game fish. F₁ hybrids have excellent growth and make trophy fish. Unfortunately backcross hybrids have lost that heterotic trait.

*Material examined.*—TNHC 1317.

*Pomoxis annularis.*—The white crappie is native to the eastern United States. It is widely used as a game fish.

*Pomoxis nigromaculatus.*—The black crappie is native to the eastern United States. It also is widely used as a game fish.

*Material examined.*—TNHC 1502.

Family Percidae

*Ammicrypta vivax.*—The scaly sand darter is native to the Austrori-
parian. Like all darters adult sand darters have a reduced swim bladder and thus are bottom fish. All are also susceptible to environmental change and evidence of human disturbances.

*Etheostoma asprigene.*—The mud darter is native to the Austroriparian.

_Etheostoma chlorosomum._—The bluntnose darter is common in the Austroriparian.

_Material examined._—TNHC 65867.

_Etheostoma fusiforme._—Like many Caddo Lake darters, the swamp darter is Austroriparian.

_Material examined._—OSUS 4731, 4732.

_Etheostoma gracile._—The slough darter is Austroriparian.

_Material examined._—TNHC 1311.

*Etheostoma histrio._—The harlequin darter lives in submerged brush piles in the Austroriparian.

_Etheostoma proeliare._—The cypress darter is Austroriparian.

_Material examined._—TNHC 927.

*Percina macrolepida._—The bigscale logperch is native to eastern Texas. It is one of the largest darters.

*Percina maculata._—The blackside darter is Austroriparian.

*Percina shumardi._—The river darters occurs in large streams in the eastern United States. It was however collected well within Caddo Lake.

*Percina sciera._—The dusky darter occurs throughout the eastern United States.

*Stizostedion vitreum._—The walleye is native to more northern waters in the United States. They have been introduced widely in Texas as a sport fish.
Family Scienidae

*Aplodinotus grunniens.*—The freshwater drum is native to the eastern United States.

**SPECIES OF PROBABLE OCCURRENCE**

Seventeen additional species are likely to occur in Caddo Lake. Other than the state fishery biologists who focus on game species, fewer than 20 collections have been taken from Caddo Lake.

*Ichthyomyzon gagei.*—The southern brook lamprey is Austroriparian. This species is non parasitic. In effect it skips the parasitic phase and dies shortly after its first breeding.

*Macroybopsis aestivalis.*—The speckled chub is Austroriparian.

*Notropis bairdi.*—The Red River shiner is native to the Red River system of Texas and Oklahoma.

*Notropis buchanani.*—The ghost shiner is native to the eastern United States.

*Notropis potteri.*—The chub shiner is native to eastern Texas and Oklahoma.

*Notropis stramineus.*—The sand shiner is native to the eastern United States.

*Phenacobius mirabilis.*—The suckermouth minnow is native to the eastern United States.

*Cycleptus elongates.*—The blue sucker is native to the Austroriparin. Populations often are reduced by dams that block spawning migrations.

*Moxostoma poecilurum.*—The blacktail red horse is native to the Austroriparian.

*Heterandria formosa.*—The least killifish is a small species in the Austroriparian.
Table 1. Numbers of known fish species in Texas localities and western states or territories. Parentheses indicate number of probable species.

<table>
<thead>
<tr>
<th>Region</th>
<th>Number of native freshwater fish</th>
<th>Number of introduced freshwater fish</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caddo Lake</td>
<td>80 (+15?)</td>
<td>4 (+3)</td>
<td>This study</td>
</tr>
<tr>
<td>Edwards Plateau</td>
<td>55</td>
<td>13</td>
<td>Hubbs et al. (1991)</td>
</tr>
<tr>
<td>Trans-Pecos</td>
<td>48 (+1?)</td>
<td>13</td>
<td>Hubbs et al. (1991)</td>
</tr>
<tr>
<td>Austroriparian</td>
<td>96</td>
<td>12</td>
<td>Hubbs et al. (1991)</td>
</tr>
<tr>
<td>Utah</td>
<td>26</td>
<td>30</td>
<td>Sigler &amp; Miller (1963)</td>
</tr>
<tr>
<td>New Mexico</td>
<td>71</td>
<td>25</td>
<td>Sublette et al. (1990)</td>
</tr>
<tr>
<td>Arizona</td>
<td>26</td>
<td>61</td>
<td>Minckley (1973)</td>
</tr>
<tr>
<td>Nevada</td>
<td>33</td>
<td>28</td>
<td>La Rivers (1994)</td>
</tr>
<tr>
<td>California</td>
<td>63</td>
<td>49</td>
<td>Moyle (1976)</td>
</tr>
<tr>
<td>Montana</td>
<td>52</td>
<td>128</td>
<td>Brown (1971)</td>
</tr>
<tr>
<td>Alberta, Canada</td>
<td>51</td>
<td>8</td>
<td>Nelson &amp; Paetz (1992)</td>
</tr>
</tbody>
</table>

*Lepomis auritus.*—The redbreast sunfish is native to east coast states. As a large sunfish it has been widely introduced in Texas.

*Lepomis humilis.*—The orangespot sunfish is a small sunfish native to the eastern United States.

*Ammocrypta clara.*—The western sand darter is Austroriparian.

*Etheostoma parvipinne.*—The goldstripe darter is Austroriparian. Its occurrence in Caddo Lake might be only near creek inlets.

*Tilapia aurea.*—Blue tilapia has escaped widely from aquaculture facilities and caused serious problems to native fishes.

*Tilapia mossambica.*—The Mossambique tilapia also has escaped from aquaculture facilities.

*Mugil cephalus.*—The striped mullet is estuarine but commonly is found far upstream in the eastern United States.

**Discussion**

The biodiversity of Caddo Lake fishes can be illustrated much more extensively by comparison with two studied Texas regions, the Edwards Plateau and Trans-Pecos (Table 1). The latter is defined to include all waters upstream from, and west, of the Rio Grande/Pecos confluence. The Edwards Plateau has 55 native and 13 introduced species. The Trans-Pecos has 48 native (and one probable) and 13 introduced species (Hubbs et al. 1991).
Additionally Caddo Lake itself has 82% of the fish species known for east Texas. This contrasts to other east Texas reservoirs that contain less than half of the east Texas fishes. State/province fish numbers also shows the regional diversity of Caddo Lake fish fauna (Table 1). The regional data cover vastly more area and isolated drainages, compared to that of Caddo Lake. Caddo Lake has more native fishes and many fewer exotics, showing it to be relatively unimpacted by fish introductions.

LITERATURE CITED


CH at: hubbs@mail.utexas.edu
MORTALITY OF BLACK BASS CAPTURED IN THREE FISHING TOURNAMENTS ON LAKE AMISTAD, TEXAS

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Total mortality of black bass (Micropterus sp.) captured in three fishing tournaments held on Lake Amistad, Texas, ranged from 0.3 to 64.8% and was directly related to water temperature. Total mortality in tournaments held in August and September 1998 (64.8 and 47.2%, respectively) was considerably greater than expected (28.3 and 24.4%, respectively) based on a model that predicts mortality as a function of water temperature. High mortality in these tournaments probably was related to unusual handling and holding procedures (August) and depressurization illness (September). Total mortality in the third tournament (0.3%), held in March 1999, was less than expected (12.0%) based on water temperature.

Competitive fishing events (fishing tournaments, derbies, tagged fish contests and other events in which anglers compete for prizes or other inducements), particularly for black bass Micropterus sp., have become an important use of freshwater fishery resources in North America (Shupp 1979; Duttweiler 1985; Schramm et al. 1991). In Texas, 18% of black bass anglers participate in fishing tournaments (Wilde et al. 1998a). Despite the popularity of fishing tournaments, tournament angling is at times a contentious issue, with anglers and fishery management agencies expressing concern for potential social and biological impacts (Schramm et al. 1991). Among Texas black bass anglers who do not participate in tournaments, 44% believe that most fish captured and released in tournaments do not survive (Wilde et al. 1998a). Also, most (51%) of these anglers believe their fishing quality is negatively impacted by tournaments.

Although tournament-associated mortality of black bass has decreased since the 1970s (Holbrook 1975; Wilde 1998), there has been little change since the 1980s. Total mortality of tournament-caught and released fish averaged 26.2% in the 1980s and 28.3% in the 1990s, although it may be substantially lower in well-conducted tournaments or those conducted in winter and spring (Wilde 1998). There remains a need to document mortality of fish captured and released in tournaments and, especially, the rules and conditions under which fishing tourna-
ments are conducted to allow a better understanding of the factors affecting tournament-associated mortality (Wilde 1998). This paper documents initial and total mortality of black bass captured and released in three Texas fishing tournaments.

**MATERIALS AND METHODS**

Mortality of black bass captured and released in three black bass fishing tournaments was studied at Lake Amistad National Recreation Area. All tournaments were "team tournaments" (Wilde et al. 1998b), in which the two anglers in each boat combine their catch, with prizes being awarded for the greatest combined (team) catch. All three tournaments were held with a five-fish daily bag-limit per team.

The first tournament was held on 8 and 9 August 1998. Fishing began at 0600 hrs on both days and ended at 1500 and 1300 hrs on the first and second days of the tournament, respectively. This tournament was held with a 381 mm minimum length limit. The weigh-in site for this tournament was at the Del Rio, Texas, Convention Center, about 18 km from Lake Amistad. At the end of the fishing day, anglers loaded their boats on trailers and drove to the weigh-in site with their catch in live wells. After fish were weighed, they were placed in hauling tanks and, at the end of the weigh-in, were trucked to Lake Amistad for release. Fish were held in these tanks for 2 to 4 hrs before their release at Lake Amistad.

The second tournament was held on 19 and 20 September 1998. Fishing began at 0600 hrs on both days and ended at 1600 and 1500 hrs on the first and second days of the tournament, respectively. This tournament was held with a 381 mm minimum length limit. The weigh-in site for this tournament was at the Diablo East marina parking lot. The weigh-in site was approximately 100 m from the lake and about 20 m above the lake surface. After weigh-in fish, were returned to the lake via a large PVC pipe (203-mm internal diameter) through which water was pumped.

The third tournament was held on 27 and 28 March 1999. Fishing began at 0600 hrs on both days and ended at 1600 and 1500 hrs on the first and second days of the tournament, respectively. This tournament was held with a 356 mm minimum length limit. There were two weigh-in and release sites at this tournament. One was at Diablo East marina parking lot described above, the other was on the lake at Spur 454, an abandoned road that terminates at the lake. The Spur 454 weigh-in site was located at the end of a small dock. After weigh-in, fish were
carried to the lake, a distance of approximately 20m, and released.

During each tournament, initial mortality (tournament-related mortality occurring prior to release) was recorded as the number and percent of dead fish brought to weigh-in. Samples of released tournament-caught fish were held in two nylon-mesh holding pens, 3 m long, 3 m wide and 3 m deep, suspended in covered slips at the National Park Service (NPS) boat dock to assess delayed mortality (tournament-related mortality occurring after release). As tournament-caught fish were being released, 62-64 largemouth bass were collected at haphazard, without knowledge of their physical condition, as they were removed from the transport truck (August tournament) or at release sites (September and March tournaments). Every attempt was made to limit the number of fish from any one boat which were held for observation of delayed mortality to two. In the August and September tournaments, half of the largemouth bass observed for delayed mortality were collected on the first day of the tournament; the remaining half was collected on the second day. In the March 1999 tournament, all fish were collected on the first day of the tournament, with half of the fish being collected from each weigh-in site. Fish collected on different days, or from different weigh-in sites, were held in separate pens.

Six to 12 hours before each tournament began, 16 control fish were captured from Lake Amistad by electrofishing. Control fish were not subjected to tournament-related stresses such as angling, holding in live wells and weigh-in and were marked by clipping the soft dorsal fin. Eight control fish were placed, at random, in either of two holding pens. Tournament-caught and control fish were held for six days to estimate delayed mortality (Wilde 1998) and dead fish were removed daily. After six days, surviving fish were released.

Initial mortality (IM) was determined as the number of fish that were dead at weigh-in divided by the total number of fish brought to weigh-in on each day. Delayed mortality (DM) was estimated separately for each day and was measured as the proportion of tournament-caught fish that died in each pen. During the course of the study, only one control fish died (associated with tournament fish captured on 19 September 1998). Although there was no significant difference ($\chi^2 = 2.1222$, $df = 1$, $P = 0.1452$) in mortality between tournament (40%) and control fish (12.5%) for that one sample, this test had low statistical power ($B < 0.60$) so the delayed mortality was adjusted for control fish mortality by subtraction. This yielded an adjusted delayed mortality of 27.5% for that day.
Total mortality (TM) for each day $i$ of the tournament was calculated as:

$$TM_i = IM_i + \left( \frac{L_i}{C_i} \times DM_i \right),$$  \hspace{1cm} (1)

where $L_i$ is the number of fish brought to weigh-in alive and $C_i$ is total number of fish, live or dead, captured and brought to weigh-in. Total mortality across all days, or weigh-in sites, was calculated as:

$$TM_{total} = \sum TM_i \times W_i,$$  \hspace{1cm} (2)

where $TM_i$ is total mortality on the $i$th tournament day (or the $i$th weigh-in site), and $W_i$ is a weighting factor, equal to the number of fish captured and weighed on the $i$th day ($C_i$) divided by the total number of fish captured ($C_{total}$) on all days (or at all weigh-in sites) of the tournament. The sampling variance of total mortality across all samples (dates or weigh-in locations), $\text{Var}(TM_{total})$, was estimated as:

$$\text{Var}(TM_{total}) = \sum \sum \text{Var}(TM_i) \times W_i^2,$$  \hspace{1cm} (3)

where $TM_i$ is total mortality on the $i$th tournament day, and $W_i$ is a weighting factor, equal to the number of fish captured and weighed on the $i$th day ($C_i$) divided by the total number of fish captured ($C_{total}$) on all $N$ days of the tournament. The standard error ($SE$) of $TM_{total}$ was obtained by taking the square root of $\text{Var}(TM_{total})$ (Cochran 1977). Estimates of mortality and standard errors were multiplied by 100 and are expressed herein as percentages.

Wilde (1998) developed regression models that allow prediction of initial and total mortality of black bass captured in fishing tournaments based on water temperature ($\text{TEMP, } ^\circ\text{C}$):

$$IM = 0.0019 \times \text{TEMP}^{2.4569}$$  \hspace{1cm} (4)

$$TM = 0.1042 \times \text{TEMP}^{1.6831}.$$  \hspace{1cm} (5)

These equations are used here to provide a basis for assessing the possible effects of tournament conditions and procedures on black bass mortality.

Before and during the August 1998 tournament, some anglers voiced concerns that high water temperatures might result in unusually high tournament-associated mortality. Therefore, tournament anglers were asked two questions as they waited to weigh their fish. Questions were asked of one person per team and were asked only on the first day of the tournament so there would be one response from each team contacted. Anglers were asked what they thought total mortality would be for the tournament. Anglers also were asked, "If mortality was found
to be ___% in this tournament, would you think this is acceptable or too high?" The blank was filled in with a randomly assigned value that ranged from 10 to 95%, in 5% increments. Logistic regression was used to model anglers' acceptance of the stated mortality.

**RESULTS AND DISCUSSION**

Initial mortality in the three tournaments studied ranged from 0.3 to 5.8% (Table 1). Based on water temperature, initial mortality in these tournaments was predicted to be 6.9 (August 1998), 5.6 (September 1998) and 2.0% (March 1999). In the August 1998 tournament, fish were held for 2-4 hours after weigh-in. As a result, 3.2% of fish that were alive at weigh-in had died by the time they were released, so total pre-release mortality for this tournament was 8.2%. In the remaining tournaments, fish were released immediately after weigh-in so pre-release mortality was equal to initial mortality.

Delayed mortality ranged between 0 and 61.6% among tournaments and was directly related to water temperature (Table 1). Combining estimates of pre-release and delayed mortality yields total mortality estimates of \(64.8 \pm 5.60\%\) (mean \(\pm SE\)) for the August 1998 tournament, \(47.2 \pm 9.16\%\) for the September tournament, and \(0.3 \pm 0.00\%\) for the March 1999 tournament. Based on water temperature, total mortality was much greater than predicted for the August (28.3%) and September tournaments (24.4%), but was less than predicted (12.0%) for the March tournament. Fish captured by anglers in all three tournaments were predominantly (> 95%) largemouth bass *M. salmoides*, but some spotted bass *M. punctulatus* also were captured. All tournament-caught fish held for observation of delayed mortality, as well as control fish, were largemouth bass; therefore, results of this study can be interpreted as providing estimates of tournament-associated mortality for largemouth bass.

Water temperature appears to be the single most important factor influencing mortality of tournament-caught fish (Wilde 1998). However, several other factors are known to affect mortality of black bass captured and released in fishing tournaments: number and size of fish captured (Meals & Miranda 1994; Weathers & Newman 1997; Wilde et al. 2002), number of participants (Schramm et al. 1985; 1987; Hartley & Moring 1995; Ostrand et al. 1999), live-well conditions (Plumb et al. 1988; Kwak & Henry 1995), and organizational effects and tournament rules (Kwak & Henry 1995; Weathers & Newman 1997; Wilde et al. 1998b; Ostrand et al. 1999).
Table 1. Initial, delayed and total mortality of black bass captured in three fishing tournaments at Lake Amistad, Texas, during August 1998 through March 1999.

<table>
<thead>
<tr>
<th>Date</th>
<th>No. of teams</th>
<th>Water temp. (°C)</th>
<th>No. of fish caught</th>
<th>No. of tournament fish held for observation</th>
<th>Total pre-release mortality (%)</th>
<th>Delayed mortality (%)</th>
<th>Total mortality (%)</th>
<th>SE total mortality (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-9 Aug. 1998</td>
<td>527</td>
<td>27.9</td>
<td>2409</td>
<td>64</td>
<td>8.2%</td>
<td>61.6</td>
<td>64.8</td>
<td>5.60</td>
</tr>
<tr>
<td>19-20 Sept. 1998</td>
<td>187</td>
<td>25.6</td>
<td>504</td>
<td>62</td>
<td>5.8%</td>
<td>44.0</td>
<td>47.2</td>
<td>9.16</td>
</tr>
<tr>
<td>27-28 Mar. 1999</td>
<td>241</td>
<td>16.8</td>
<td>506</td>
<td>64</td>
<td>0.3%</td>
<td>0.0</td>
<td>0.3</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Among the tournaments studied at Lake Amistad, a combination of high water temperatures, overland transportation in live wells, and the holding period of 2-4 hours prior to release most likely are responsible for the high mortality observed in the August 1998 tournament. Unexpectedly high mortality in the September 1998 tournament may be related to the depth at which fish were captured. Total mortality among fish captured on the first day of this tournament (31.6%) was slightly greater than that predicted (24.4%) based on water temperature; however, total mortality among fish captured on the second day of the tournament (73.5%) was substantially greater than predicted (24.4%). Tournament participants reported that most fish captured on the second day of the tournament were taken from waters deeper than 9 m. Black bass captured from this depth would be expected to show signs of depressurization sickness (Feathers & Knable 1983), which include a distended abdomen and swollen air bladder that can cause death. Observation of black bass floating at the lake surface, struggling to submerge, at the release site is evidence of depressurization sickness among these fish. Overland transport of fish in the August tournament and depressurization sickness in the September tournament probably account for the large discrepancies between observed mortality and that predicted by Wilde’s (1998) regression models.

Tournament anglers’ estimates of total mortality for the August 1998 tournament ranged from 2 to 95% (mean = 29.7%, SE = 2.76, N = 77). Logistic regression of the acceptability of different rates of mortality to anglers was highly significant (Fig. 1. $\chi^2 = 11.096$, df = 1, $P < 0.0001$). Based on the logistic regression, 28% total mortality (predicted based on water temperature at the time of the tournament) would be acceptable to only 33% of tournament anglers, 30% total mortality (the average of anglers estimates) would be accepted to 28% of tournament anglers, and 65% total mortality (observed) would be acceptable to only 10% of tournament anglers.
Total mortality observed at two of the three black bass fishing tournaments studied were near (September, 47.2%) or exceeded (August, 64.8%) 50%, a level that was acceptable to fewer than 20% of tournament anglers. This level of mortality also is consistent with the belief held by many nontournament anglers that most tournament-caught fish do not survive (Wilde et al. 1998a). Although there remains some question whether tournament-associated mortality is harmful to black bass populations (e.g., Schramm et al. 1991), results of this study suggest the need for continued improvement of tournament rules and procedures to reduce mortality to a level acceptable to both tournament and nontournament anglers.

ACKNOWLEDGMENTS

We thank Bill Sontag, Todd Brindle and Joe Kraai for logistical support; Jimmy Dean, John Dennis and Bob Zerr, for help in collecting control fish; Tim Bonner, Ken Ostrand, Kevin Pope and Gregory Wilde for help in various portions of the study; and Ron Hilliard, Dane Widner and Harvey Holmes for assistance in collecting information at their tournaments. We also thank David O’Keefe and other Del Rio, Texas, sportsmen for partial financial support of this work. This is contribution
LITERATURE CITED


GRW at: gene.wilde@ttu.edu
THEROPOD DINOSAUR TRACKWAYS IN THE LOWER CRETACEOUS (ALBIAN) GLEN ROSE FORMATION, KINNEY COUNTY, TEXAS

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Southern Methodist University
Dallas, Texas 75275

Abstract.—Two parallel theropod dinosaur trackways are preserved in the Albian Glen Rose Formation of Kinney County in southwest Texas. Although track size and depth indicate that one of the trackways represents a larger, heavier dinosaur, track morphology of the two trackways is similar. The tracks are referred to *Grallator* sp. Gregarious behavior is suggested by the direction of travel and uniform spacing of the trackways; however, speed estimates calculated utilizing stride and footprint length indicate that the trackmakers were moving at different speeds.

Dinosaur trackways are common in Texas, known from at least 50 locations (Pittman 1992). One of the more famous of the Texas trackways is now on display at the American Museum of Natural History. This trackway, recovered from the bed of the Paluxy River in what is now Dinosaur Valley State Park in Somervell County, Texas, has been interpreted to document the attack of a predatory theropod, probably *Acrocanthosaurus*, on its sauropod prey (Thomas & Farlow 1997). This unique interpretation illustrates how behavior can be inferred from trackway analyses.

Trackways can provide evidence for gregarious behavior in dinosaurs, which is usually inferred from the occurrence of a number of tracks oriented in the same direction. This is commonly seen in sauropod track sites, such as the Davenport Ranch in Bandera County, Texas, that records the movements of a herd of at least twenty-three sauropods (Lockley & Hunt 1995). Similar records of herding behavior are reported for herbivorous bipedal ornithopod dinosaurs (Ostrom 1972). Upper Cretaceous Western Interior Seaway coastal plain deposits of the Dakota Group in New Mexico and Colorado contain trackways of ornithopod herds in such abundance that the region is known as the Dinosaur Freeway (Lockley & Hunt 1995). Trackway evidence for gregarious behavior among theropod dinosaurs is less common, usually inferred from the occurrence of parallel tracks of two or more theropods found oriented in the same general direction as non-theropod (prey) dinosaur tracks. Lockley (1991) reported the occurrence of trackways
from the Late Cretaceous of Bolivia that apparently represent a group of theropods following a sauropod herd. Dinosaur Valley State Park in Texas has a series of trackways that have been interpreted as evidence of three theropods following a herd of 12 sauropods (Lockley 1991). Farlow (1987) interpreted these trackways as showing only a single theropod following the sauropods.

Paired theropod dinosaur trackways are exposed near the top of the Glen Rose Formation in an ephemeral branch of Live Oak Creek along the eastern edge of Kinney County in southwest Texas (Fig. 1). The site, SMU loc. 330, was made available for this study by Mr. Tom Masterson. This study documents the trackways, which were produced by two theropod dinosaurs moving in the same direction, maintaining a consistent spatial separation, and taking strides of equal length.

MATERIALS AND METHODS

The site was worked during two visits in 1999-2000. Excavation uncovered additional tracks of the easternmost trackway (2c and 2d). The tracks were individually measured, photographed and mapped in accordance with Lockley & Hunt (1995). Site location data is on file at the Shuler Museum of Paleontology, Southern Methodist University, Dallas, Texas (SMU loc. 330).

GEOLOGICAL SETTING

The Glen Rose Formation crops out along with other Lower Cretaceous sediments in a sinusoidal northeast to southwest trending band across the center of Texas and into Oklahoma. The Glen Rose Formation consists of a wedge of limestones, dolomites and sandstones, representing a variety of depositional environments ranging from transitional shoreline tidal flats and marshes to open marine. This diversity is the result of the transgressive/regressive nature of encroaching Albian seas that deposited the Trinity Group prior to the initial completion of the Western Interior Seaway (Pittman 1992). The Trinity Group is composed of the Twin Mountains, Glen Rose and Paluxy Formations. The Glen Rose is underlain by the terrigenous clastics of the Twin Mountains, with which it has a gradational contact, and is unconformably overlain by the Paluxy, a package of loosely consolidated sediments that ranges from continental clastics to deltaic and beach deposits. In north central Texas the Glen Rose Formation wedge pinches out and disappears, and the merged Twin Mountains and Paluxy Formations are termed the Antlers Formation (Hayward & Brown 1967).
Figure 1. (a) Map of the SMU loc. 330 theropod trackway site. The trackways are preserved on a bedding plane that was exposed by intermittent runoff erosion. An undetermined portion of trackway 2 is covered by overburden. (b) Texas map showing location of SMU loc. 330 (scale bar equals 2 meters).

The Glen Rose is subdivided into three members, the lower, middle (or Thorp Spring) and the upper member (Davis 1974). Many trackways in the Glen Rose Formation are distributed within the top of the upper Glen Rose Formation, extending over a large area representing an ancient coastal plain (Lockley & Hunt 1995), including the trackways at SMU loc. 330 (Pittman 1992). The Albian age of the upper Glen Rose is derived from ammonite biostratigraphic zones (Jacobs & Winkler 1998).

RESULTS AND DISCUSSION

Two parallel tridactyl trackways are preserved, indicating a direction of movement of 182°. The western trackway, designated trackway 1,
The tracks represent a theropod morphology commonly recorded from the Glen Rose Formation. They are distinguished by long, slender toe marks. Phalangeal pads are not well defined. Distal digit imprints are deeper than the mid-foot print. In well-preserved tracks of both trackways, the middle digit (III) is turned medially toward the opposing foot (Fig. 2). Digits II and IV diverge from the longitudinal axis of the foot at about 25 degrees (Table 1). Distinct claw imprints are evident on tracks 1a, 1c, 1e and 2d. There is no impression of the hallux. A distinct heel imprint is apparent.

Preservation and depth among the tracks varies. Tracks 1a-1d are shallower than the others of that trackway (Table 2). There is no evidence of preserved skin impressions in any track. Prints of trackway 2 are deeper, longer and wider than of trackway 1. Average depth of
Table 1. Digit divarication angles. Measurements are in compass degrees.

<table>
<thead>
<tr>
<th>Track Number</th>
<th>Digit Divarication angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>24</td>
</tr>
<tr>
<td>1b</td>
<td>26</td>
</tr>
<tr>
<td>1c</td>
<td>24</td>
</tr>
<tr>
<td>1d</td>
<td>25</td>
</tr>
<tr>
<td>1e</td>
<td>24</td>
</tr>
<tr>
<td>1f</td>
<td>28</td>
</tr>
<tr>
<td>1g</td>
<td>24</td>
</tr>
<tr>
<td>1h</td>
<td>25</td>
</tr>
<tr>
<td>Mean</td>
<td>25.0</td>
</tr>
<tr>
<td>2a</td>
<td>28</td>
</tr>
<tr>
<td>2b</td>
<td>24</td>
</tr>
<tr>
<td>2c</td>
<td>24</td>
</tr>
<tr>
<td>2d</td>
<td>25</td>
</tr>
<tr>
<td>Mean</td>
<td>25.3</td>
</tr>
</tbody>
</table>

Table 2. Individual tracks dimensions: W = width, L = length, D = depth. All measurements are in centimeters.

<table>
<thead>
<tr>
<th>Track Number</th>
<th>W</th>
<th>L</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>32</td>
<td>50</td>
<td>2</td>
</tr>
<tr>
<td>1b</td>
<td>31</td>
<td>50</td>
<td>3</td>
</tr>
<tr>
<td>1c</td>
<td>29</td>
<td>49</td>
<td>4</td>
</tr>
<tr>
<td>1d</td>
<td>32</td>
<td>38</td>
<td>1</td>
</tr>
<tr>
<td>1e</td>
<td>33</td>
<td>50</td>
<td>6</td>
</tr>
<tr>
<td>1f</td>
<td>34</td>
<td>50</td>
<td>5</td>
</tr>
<tr>
<td>1g</td>
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<td>46</td>
<td>6</td>
</tr>
<tr>
<td>1h</td>
<td>33</td>
<td>46</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>32.3</td>
<td>47.4</td>
<td>4.0</td>
</tr>
<tr>
<td>2a</td>
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<td>55</td>
<td>7</td>
</tr>
<tr>
<td>2b</td>
<td>34</td>
<td>60</td>
<td>7</td>
</tr>
<tr>
<td>2c</td>
<td>36</td>
<td>55</td>
<td>8</td>
</tr>
<tr>
<td>2d</td>
<td>35</td>
<td>55</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>35.5</td>
<td>56.3</td>
<td>7.0</td>
</tr>
</tbody>
</table>

trackway 2 prints is 7 cm, of trackway 1 prints, 4.4 cm. The deeper prints of trackway 2 preserve greater detail of foot morphology (Fig 3), including footpads that presumably correspond with phalangeal joints. Digit divarication angle is similar to trackway 1, about 25 degrees. There is evidence of upward displacement of sediments between joints
and digits not seen in the shallower prints of trackway 1. Trackway 2 prints average 9% wider and 8.7% longer than trackway 1 prints. The two trackmakers were of dissimilar size and weight.

Langston (1974) referred theropod tracks from the Glen Rose to the ichnotaxa *Irenesauripus* (Sternberg 1926), and mentions the theropod *Acrocanthosaurus* as a trackmaker candidate. *Acrocanthosaurus* body fossils are reported from the Twin Mountains Formation of Texas (Harris 1998) and the Antlers Formation of Oklahoma (Stovall & Langston 1950; Currie & Carpenter 2000). Pittman (1992) referred tridactyl tracks from the Glen Rose to the theropod ichnotaxa *Grallator* (Hitchcock 1858), and noted that *Irenesauripus* displays character states diagnostic of *Grallator*. *Grallator* is a bird-like print, characterized by a mediately turned digit III, which usually exhibits preserved footpad impressions (Pittman 1992). *Eubrontes* (Hitchcock 1845) a theropod ichnotaxa typically larger in size than *Grallotor* but exhibiting similar overall morphology, was originally considered by Olsen (1980) to be synonymous with *Grallator*. Recent morphometric analyses indicate
Table 3. Trackway dimensions. Pace length is the distance between the same point on successive footprints of a trackway (left, right); stride length is the distance between the same point on successive same foot footprints (left, left, or right, right); pace angulation measures the angle formed by drawing a line from the most anterior tip of the middle digit of three successive footprints (left, right, left, or right, left, right). All measurements are in centimeters. Dashes indicate non-measured dimensions.

<table>
<thead>
<tr>
<th>Tracks</th>
<th>Pace Length</th>
<th>Tracks</th>
<th>Pace Angulation</th>
<th>Tracks</th>
<th>Stride Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>la,lb</td>
<td>160</td>
<td>la,lb,lc</td>
<td>169</td>
<td>la,lc</td>
<td>321</td>
</tr>
<tr>
<td>lb,lc</td>
<td>161</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>lc,ld</td>
<td>162</td>
<td>lc,ld,le</td>
<td>170</td>
<td>lc,le</td>
<td>323</td>
</tr>
<tr>
<td>ld,le</td>
<td>161</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>le,lf</td>
<td>161</td>
<td>le,lf,lg</td>
<td>169</td>
<td>lf,lh</td>
<td>322</td>
</tr>
<tr>
<td>lg,1h</td>
<td>161</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mean</td>
<td>161.0</td>
<td>169.3</td>
<td>322.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2a,2b</td>
<td>161</td>
<td>2a,2b,2c</td>
<td>155</td>
<td>2a,2c</td>
<td>322</td>
</tr>
<tr>
<td>2b,2c</td>
<td>161</td>
<td>2b,2c,2d</td>
<td>155</td>
<td>2b,2d</td>
<td>322</td>
</tr>
<tr>
<td>2c,2d</td>
<td>161</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Mean</td>
<td>161.0</td>
<td>155.0</td>
<td>322.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

that the two ichnotaxa exhibit proportional differences that allow them to be differentiated (Olsen et al. 1998). The SMU loc. 330 trackways appear to represent both *Grallator* (trackway 1) and *Eubrontes* (trackway 2). They exhibit variable preservation of a single body morphology caused by disparities in the size and mass of the trackmakers and differences in the substrate. Following Olsen (1998) and Pittman (1992), the trackways are here referred to *Grallator*, with *Irenesauripus* considered a *Grallator* synonym.

While the individual SMU loc. 330 tracks exhibit commonly observed theropod morphology, the trackways are parallel for the length of their concurrent exposure, and have identical pace and stride lengths (Table 3). Mean pace angulation of trackway 2 is more acute than trackway 1 (155° as compared to 169.3°), which indicates a greater displacement between the left and right limbs and provides further evidence of a size differential between the two trackmakers.

Hip height of bipedal trackmakers can be estimated using morphometric ratios derived from measurements of bipedal dinosaur skeletons (Alexander 1976; Thulborn 1989). This hip height estimate can then be combined with stride length to produce a stride length/hip height ratio (λ/h). Alexander (1976) demonstrated that in living terrestrial verte-
brates the λ/h ratio for a walking gait is <2.0, for trotting or running > 2.0, and suggested the same was true for dinosaurs. The λ/h ratio for SMU loc. 330 trackways 1 and 2 is 1.34 and 1.19 respectively, indicating both trackmakers were moving at a walk.

Farlow (1981) estimated speeds for theropod dinosaurs from trackways in the Glen Rose Formation of Kimble County, Texas, using methods from Alexander (1976). Estimates ranged from 1.8 to 11.9 m s\(^{-1}\), with 12 of 15 estimates falling within the 1.8 to 3.4 m s\(^{-1}\) range. Applying this method to the SMU 330 trackway 1 produced an estimated speed of 2.6 m s\(^{-1}\); trackway 2 speed is estimated at 1.8 m s\(^{-1}\). These speeds fall within the walking speed estimates for bipedal dinosaurs provided by Thulborn (1982).

**CONCLUSIONS**

The SMU loc. 330 trackways were produced by a pair of theropod dinosaurs walking in the same direction. The tracks are referred to the ichnogenus *Grallator*. The absence of appropriately sized theropod body fossils other than *Acrocanthosaurus* within the Glen Rose Formation and other Trinity Group sediments suggests that this taxon likely made the trackways at SMU loc. 330, a conclusion in concurrence with Farlow (2001).

Estimated speed of the trackmakers agrees with previous estimates from Glen Rose Formation trackways. Although the consistent direction and equal spacing of the trackways appear to suggest gregarious behavior, speed estimates for the two trackmakers differ, which indicates that if the trackmakers were moving in concert, they were not doing so at the same speed during the interval represented by the tracks. Varying preservation between the two trackways suggests they may have been made at different times.

**ACKNOWLEDGMENTS**

Grateful acknowledgment is made of the gracious hospitality of Ann and Tom Masterson of Houston, Texas, who provided access to their property as well as food and lodging to the author during this study. Thanks also to Drs. Dale Winkler and Louis Jacobs of Southern Methodist University who reviewed this manuscript and made helpful suggestions.
Literature Cited


Hitchcock, E. 1845. An attempt to name, classify, and describe the animals that made the fossil footprints of New England. Sixth Annual Meeting of the Association of American Geologists and Naturalists: 23-25.


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REPRODUCTION IN THE COACHWHIP, 
MASTICOPHIS FLAGELLUM (SERPENTES: COLUBRIDAE),
FROM ARIZONA

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Abstract.—Reproductive tissue was examined from 145 sexually mature Masticophis flagellum museum specimens from Arizona. Males follow a seasonal testicular cycle in which individuals undergoing spermiogenesis were found April to November. Males with regressed testes were found March-July and December. Males with testes in recrudescence occurred March-August. The female reproductive activity season encompassed April-July. Fifty-three percent of the females sampled from this period were reproductively active. Mean clutch size for nine females was $7.2 \pm 3.0$ SD, range = 2-12. The finding of one female with a clutch size of two is a new minimum clutch size for M. flagellum.

The coach whip, Masticophis flagellum ranges through the southern half of the United States from coast to coast, south to the tip of Baja California and Querétaro, Mexico from below sea level to around 2350 m (Stebbins 1985). It frequents a variety of habitats including desert, prairie, scrubland, juniper-grassland, woodland, thornforest and farmland (Stebbins 1985) and has a diurnal activity period (Stebbins 1954). There are many anecdotal reports of reproduction in this species containing information on clutch sizes and mating time in different parts of its range (Force 1930; Brennan 1934; Marr 1944; Clark 1949; Werler 1951; Guidry 1953; Zweifel & Norris 1955; Wright & Wright 1957; Carpenter 1958; Minton 1958; Cunningham 1959; Tennant 1984; Stebbins 1985; Degenhardt et al. 1996). The purpose of this paper is to provide information on the ovarian and testicular cycles of M. flagellum from Arizona from a histological examination of preserved museum specimens. Comparisons are made with the reproductive cycles of other North American species of Masticophis.

MATERIALS AND METHODS

A sample of 145 sexually mature specimens of M. flagellum (54 females, mean snout-vent length, SVL = 942 mm ± 102 SD, range = 750-1152 mm; 91 males, SVL = 1003 mm ± 152 SD, range = 642-1527 mm) from Arizona was examined from the herpetology
collections of Arizona State University, Tempe (ASU), The Natural History Museum of Los Angeles County, Los Angeles (LACM) and The University of Arizona, Tucson (UAZ). Snakes were collected during the years 1950-2000. Over half of the snakes 76/145 (52%) came from Pima County, Arizona. A \( t \) test was used to compare means of female and male body sizes (SVL’s). Counts were made of enlarged ovarian follicles (\( > 12 \) mm length) or oviductal eggs. The left testis, vas deferens and a portion of the kidney were removed from males; the left ovary was removed from females for histological examination. Slides with tissue sections were stained with Harris’ hematoxylin followed by eosin counterstain. Testis slides were examined to determine the stage of the testicular cycle; ovary slides were examined for the presence of yolk deposition (secondary yolk deposition \textit{sensu} Aldridge 1979). It was common to observe autolytic changes in the kidneys of road killed specimens, whereas structures in the testis and vas deferens appeared normal. Data on the kidney sexual segment are not presented due to difficulty in distinguishing whether enlargement of kidney tubules from some males was due to reproductive activity or autolytic changes from inadequate fixation or decay prior to fixation (road kills). Because some of the specimens were road kills, not all tissues were available for histological examination due to damage or autolysis. Number of specimens examined by reproductive tissue were: ovary = 54, testis = 91, vas deferens = 79. Since the \textit{M. flagellum} samples were from different areas, there is the possibility that reproductive data of large samples from geographic or taxonomic subpopulations may differ distinctly from the pattern described herein.

\textit{Material examined.}—The following sexually mature specimens of \textit{Masticophis flagellum} from Arizona were examined: COCHISE COUNTY, (UAZ 25167, 25168, 25183, 25529, 25547, 25566, 25568, 25595, 25607, 32434, 33006, 34529, 38097, 41646, 46286, 46529, 46624, 46627, 46649, 50039, 52031); GILA COUNTY, (UAZ 25166); GRAHAM COUNTY, (UAZ 25559, 50337); MARICOPA COUNTY, (ASU 1403, 1675, 14033, 14035, 14093, 14373, 22469, 23617, 23618, 24304, 24382, LACM 125263, UAZ 37430, 40352, 44078); MOHAVE COUNTY, (ASU 24368, LACM 145267, UAZ 40087, 40356, 44859, 44860); LA PAZ COUNTY, (UAZ 35870); PIMA COUNTY, (LACM 64299, 103116, UAZ 23927, 25132, 25169, 25170, 25172, 25175, 25176, 25178, 25185, 25187, 25188, 25191, 25198-25200, 25203, 25213, 25216, 25218, 25219, 25271, 25520, 25521, 25523, 25537, 25539, 25541, 25543, 25544, 25548, 25551, 25556, 25557, 25561, 25562, 25576-25578, 25596, 25598-25600, 25609,
Testicular histology was similar to that reported by Goldberg & Parker (1975) for two colubrid snakes, *Masticophis taeniatus* and *Pituophis catenifer* (= *P. melanoleucus*). In the regressed testes, seminiferous tubules contained spermatogonia and Sertoli cells. In recrudescence, there was renewal of spermatogenic cells characterized by spermatogonial divisions; primary and secondary spermatocytes were typically present. Spermatids were occasionally seen. In spermiogenesis, metamorphosing spermatids and mature sperm were present. Males undergoing spermiogenesis were found April-November. Males with regressed testes were found March-July and December. Males with testes in recrudescence were found March-August (Table 1). The smallest reproductively active male (spermiogenesis, sperm in vas deferens) measured 642 mm SVL. As this was the smallest male examined, there may be yet smaller reproductively mature male *M. flagellum* in Arizona. Vasa deferentia of 79/79 (100%) males contained sperm: March (5); April (16); May (22); June (7); July (11); August (4); September (5); October (6); November (2); December (1). The presence of sperm in the vasa deferentia suggests *M. flagellum* has the potential of mating throughout the activity season, although previously reported matings occurred in spring (Wright & Wright 1957; Minton 1958; Degenhardt et al. 1996) and late summer (August) (Zweifel & Norris 1955). Males were significantly larger than females, \( t = 2.60; 143 \text{ df}; P = 0.01 \).

The testicular cycle of *M. flagellum* was similar to that of *Masticophis bilineatus* which was studied by Goldberg (1998). In *M. bilineatus*, males undergoing spermiogenesis were found in both spring and fall. These cycles differ from those reported for the congeners *Masticophis lateralis* (Goldberg 1975) and *M. taeniatus* (Goldberg & Parker 1975) in which spermiogenesis was restricted to fall and testes were regressed.
Table 1. Monthly distribution of stages in the seasonal testicular cycle of *Masticophis flagellum* from Arizona from examination of 91 adult museum specimens. Values shown are the numbers of males exhibiting each of the three conditions.

<table>
<thead>
<tr>
<th>Month</th>
<th>n</th>
<th>Regressed</th>
<th>Recrudescence</th>
<th>Spermiogenesis</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>18</td>
<td>3</td>
<td>13</td>
<td>2</td>
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<tr>
<td>May</td>
<td>27</td>
<td>3</td>
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<td>9</td>
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<tr>
<td>June</td>
<td>8</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>July</td>
<td>13</td>
<td>2</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>August</td>
<td>4</td>
<td>0</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>September</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>October</td>
<td>7</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>November</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>December</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

in spring, containing spermatogonia and Sertoli cells. Most of the *M. bilineatus* in Goldberg (1998) were from southern Arizona where both *M. flagellum* and *M. bilineatus* may be sympatric. Whether the prolonged periods of spermiogenesis of *M. flagellum* and *M. bilineatus* are a response to the climate of southern Arizona (see Lowe 1964) and the resultant food availability from both summer and winter rainfall must await further study.

The smallest reproductively active *M. flagellum* female (enlarged follicles > 12 mm length) measured 781 mm SVL. Females smaller than this size (several were examined) were excluded from the study to avoid including immature females in analysis of the ovarian cycle. There was no suggestion (oviductal eggs and ovarian follicles with yolk deposition in the same female) to suggest *M. flagellum* produces more than one clutch in a reproductive season.

Females with enlarged follicles (> 12 mm length) or oviductal eggs were found April-July (Table 2). Females undergoing early yolk deposition = secondary yolk deposition (*sensu* Aldridge 1979) were found in April-May and November. It is not known if the yolked follicles of the one November female would have been used in a clutch the following year or would have been reabsorbed (atresia). The timing of the ovarian cycle of *M. flagellum* from Arizona, with eggs likely being deposited in May through July, appears in synchrony to that which
Table 2. Monthly distributions of stages in the seasonal ovarian cycle of *Masticophis flagellum* from Arizona from examination of 54 adult museum specimens. Values shown are the numbers of females exhibiting each of the four conditions.

<table>
<thead>
<tr>
<th>Month</th>
<th>n</th>
<th>Inactive</th>
<th>Early yolk deposition</th>
<th>Enlarged follicles &gt; 12 mm length</th>
<th>Oviductal eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>6</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>13</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>June</td>
<td>7</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>July</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>September</td>
<td>9</td>
<td>9</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

has been reported in the literature for this species (Force 1930; Brennan 1934; Marr 1944; Clark 1949; Werler 1951; Guidry 1953; Carpenter 1958; Cunningham 1959). Tennant (1984) reported *M. flagellum* usually deposited eggs in June and July in Texas. Females of three other species of *Masticophis* had similar periods of female reproductive activity: *Masticophis lateralis* April-July (Goldberg 1975); *M. taeniatus* May-July (Parker & Brown 1980); *M. bilineatus* April-July (Goldberg 1998).

Mean clutch size for nine *M. flagellum* females was $7.2 \pm 3.0$ SD, range = 2-12. Clutch size data is summarized in Table 3. Sample size is inadequate to determine whether a SVL-clutch size relationship exists for *M. flagellum*. Fitch (1970) calculated a mean clutch size of 10.1 for eleven clutches (range 4-16) taken from the literature. Tennant (1984) and Stebbins (1985) gave what are apparently maximum clutch sizes of 20 eggs for *M. flagellum*. There are reports of clutches of four eggs (Marr 1944; Wright & Wright 1957; Tennant 1984; Stebbins 1985) hence the clutch of two eggs (Table 3) is a new minimum clutch size for *M. flagellum*.

Only a portion of *M. flagellum* females (16/30) 53% showed evidence of reproduction (Table 2) during the period of reproductive activity. That not all members of the female population produce eggs in a given year has been reported for other North American colubrid snakes, for
Table 3. Clutch sizes for 9 *Masticophis flagellum* from Arizona (estimated from counts of yolked follicles > 12 mm length or oviductal eggs) from museum specimens.

<table>
<thead>
<tr>
<th>Date</th>
<th>SVL (mm)</th>
<th>Clutch size</th>
<th>County</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>29 April</td>
<td>990</td>
<td>10</td>
<td>Pima</td>
<td>UAZ 25218</td>
</tr>
<tr>
<td>15 May</td>
<td>781</td>
<td>2</td>
<td>Mohave</td>
<td>UAZ 40356</td>
</tr>
<tr>
<td>16 May</td>
<td>1015</td>
<td>9</td>
<td>Cochise</td>
<td>UAZ 33006</td>
</tr>
<tr>
<td>22 May</td>
<td>873</td>
<td><em>a</em></td>
<td>Pima</td>
<td>UAZ 25578</td>
</tr>
<tr>
<td>28 May</td>
<td>1009</td>
<td>4</td>
<td>Pinal</td>
<td>UAZ 25220</td>
</tr>
<tr>
<td>29 May</td>
<td>1125</td>
<td>12</td>
<td>Pinal</td>
<td>UAZ 25536</td>
</tr>
<tr>
<td>3 June</td>
<td>985</td>
<td>7</td>
<td>Pima</td>
<td>UAZ 25598</td>
</tr>
<tr>
<td>4 June</td>
<td>981</td>
<td><em>b</em></td>
<td>Cochise</td>
<td>UAZ 25568</td>
</tr>
<tr>
<td>12 June</td>
<td>842</td>
<td>6</td>
<td>Mohave</td>
<td>UAZ 44859</td>
</tr>
<tr>
<td>13 June</td>
<td>853</td>
<td>8c</td>
<td>La Paz</td>
<td>UAZ 35870</td>
</tr>
<tr>
<td>15 July</td>
<td>855</td>
<td>7</td>
<td>Pima</td>
<td>LACM 103116</td>
</tr>
</tbody>
</table>

* Part of clutch was missing.

b Snakes with coagulated yolk, follicles could not be counted.

c Oviductal eggs, all other females contained enlarged follicles.

example see Goldberg (2000a; 2000b) and Goldberg & Rosen (1999). However, in contrast, Parker & Brown (1980) reported 13/14 (93%) *M. taeniatus* from late May-early July from northern Utah were gravid and that annual reproduction was normal for this species.

While some information on snake reproduction can be obtained by histological examination of museum specimens, field studies will be required to elucidate other aspects of *M. flagellum* reproductive biology such as ages when sexual maturity occurs and frequency of clutch production by females. Since the range of *M. flagellum* extends through the southern portion of the United States from coast to coast (Stebbins 1985), examination of the reproductive cycle from eastern populations would provide information on variation in reproduction within the same species from different environments.

ACKNOWLEDGMENTS

I thank Michael E. Douglas (formerly of Arizona State University), David A. Kizirian (Natural History Museum of Los Angeles County) and Charles H. Lowe (University of Arizona) for permission to examine *M. flagellum*. 
Literature Cited


Werler, J. E. 1951. Miscellaneous notes on the eggs and young of Texan and Mexican...

SRG at: sgoldberg@whittier.edu
Mitochnodrial DNA analysis of gene flow among six populations of collared lizards (Crotaphytus collaris) in west central Texas

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Abstract.—Gene flow among six populations of the collared lizard (Crotaphytus collaris) was estimated using restriction endonuclease analysis of a segment of the mitochondrial genome. Individuals (n = 37) were collected from O. C. Fisher Lake (n = 6), Twin Buttes Reservoir (n = 4), E. V. Spence Reservoir (n = 2), Ballinger Municipal Lake (n = 4), Carter Ranch (n = 6) and Sims Ranch (n = 15) in Tom Green, Runnels, Coke and Concho counties of west central Texas. Wagner parsimony analysis revealed gene flow between O. C. Fisher Lake and Twin Buttes Reservoir, from Carter Ranch to O. C. Fisher Lake and from Carter Ranch to both Ballinger Municipal Lake and E. V. Spence Reservoir. Sims Ranch individuals displayed no well-supported gene flow affiliations with any other population sampled. It is likely that the Carter and Sims Ranch populations are ancestral to the other populations sampled.

Gene flow is an important consideration when examining the population structure of any organism over time. Movement of genetic material between populations of organisms causes them to become more similar in overall genetic composition. Perhaps more importantly, gene flow results in increased genetic heterozygosity that may allow the organisms to better cope with selection pressures. Isolated populations that receive little or no genetic exchange with other populations may experience loss of heterozygosity (inbreeding depression) and encounter a reduced ability to endure selection pressures. Alleles within isolated populations may be driven to fixation through genetic drift or founder effect. However, outbreeding depression can also occur when gene flow disrupts highly specialized adaptive complexes that have been obtained through strong selection pressures associated with some habitats (Templeton et al. 1990).

While much work has been done on geographic variation in sexual dimorphism in the collared lizard, Crotaphytus collaris, by McCoy et al. 1994, McCoy 1995, McCoy et al. 1997 and Baird et al. 1997, only limited work has been conducted on gene flow in this species. The
opportunity for genetic divergence and speciation was postulated in a study by Sexton et al. (1992). This postulate supported the findings of Templeton et al. (1990) when highly fragmented populations of *Crotaphytus collaris* were studied in the Ozark Mountains. Using both protein and nucleic acid assays, Templeton et al. (1990) noted a lack of gene flow among these isolated populations. Inbreeding depression and genetic drift are postulated to greatly increase the probability of local extinctions in these populations. Templeton et al. (1990) goes on to cite circumstantial evidence for local extinctions that have already occurred. Yoshioka (1996) found evidence of strong gene flow among collared lizards in central Oklahoma populations. In addition, gene flow was stronger among more closely-arranged populations than those distantly spaced. Hranitz & Baird (2000) supported these conclusions in populations in central Oklahoma. Moreover, it was found that effective population size was small, and hence, genetic drift could have profound effects on collared lizard populations. However, gene flow was reported to be sufficiently strong to avoid divergence through genetic drift, and therefore, local extinctions (Hranitz & Baird 2000).

The current study is the first attempt to measure gene flow among populations of *Crotaphytus collaris* in unfragmented habitats using mtDNA. In addition, no gene flow studies have been performed in Texas populations. Two ranch sites and four lake sites were used for lizard collection. Because these lakes vary in age, the effect of age on gene flow can be determined. The O. C. Fisher Lake is located northwest of San Angelo, Texas, and was completed in 1951 (Wilde pers. comm.). Twin Buttes Reservoir is southwest of San Angelo and was completed in 1963 (Thornton pers. comm.). Farther northwest of San Angelo than O. C. Fisher Lake is the E. V. Spence Reservoir, which was completed in 1969 (Thornton pers. comm.). Lastly, the Ballinger Municipal Lake is far northeast of San Angelo and was completed in 1984 (New pers. comm.).

**METHODS AND MATERIALS**

Lizards (*n*=37) were captured from six local populations in Tom Green, Runnels, Coke and Concho counties including the Sims Ranch near Paint Rock (*n*=15), the Carter Ranch near Mertzon (*n*=6), E. V. Spence Reservoir near Robert Lee (*n*=2), O. C. Fisher Lake in San Angelo (*n*=6), Twin Buttes Reservoir in San Angelo (*n*=4) and Ballinger Municipal Lake near Ballinger (*n*=4). After capture, lizards were euthanized with sodium pentobarbital, autopsied and all parasites
were removed. Approximately 60 μL of whole blood was drawn from the orbital sinus (MacLean et al. 1973) of each lizard prior to euthanasia. Blood samples were stored at -70°C in blood buffer (10.0 mM Tris, 1.0 mM EDTA, 120.0 mM NaCl). Digestions consisted of 20 μL of blood, 90 μL of lysis buffer (10.0 mM Tris, 1.0 mM EDTA, 120.0 mM NaCl, 0.2% SDS), 50 μL proteinase K (6.0 mg/mL), and 3.0 (1 CaCl₂ (100 mM). Digestions were incubated at 35°C for 36-48 hours. DNA was harvested from the resulting blood lysate using a standard phenol-chloroform extraction (Mullebach et al. 1989; Sambrook et al. 1989). Harvested DNA was visualized on 1.0% (w/v) agarose gels stained with ethidium bromide. Samples of satisfactory quality were quantified with a mass spectrophotometer (Sambrook et al. 1989).

The mitochondrial genome of the collared lizard was chosen for study because of its strictly maternal mode of transmission and highly conserved nature (Avise 1986; 1994; Cronin 1991; Cronin et al. 1993). An approximately 2400 base pair (bp) region of the NADH dehydrogenase gene (Lee et al. 1994) was amplified using the polymerase chain reaction (PCR) (Sambrook et al. 1989) and primers from Lee et al. (1994). Optimal reagent concentrations per reaction (50 μL) were: 50 ng of DNA, primers (5'-TAA GCT ATC GGG CCC ATA CC-3', 5'-ACT TCA GGG TGC CCA AAG AAT CA-3') at 0.1 μM each, MgCl₂ at 0.5 mM, dNTP's at 2.2 μM, reaction buffer at 1X, and 2.5 units (U) Taq polymerase. Each reaction consisted of 30 cycles (88°C for 45 sec, 58°C for 45 sec, 72°C for 2 min).

Amplicons were digested with 12 restriction endonucleases (Avise et al. 1979; Lansman et al. 1981), including Cfo I, Hpa II, Sau 96 I, Rsa I, Hin d III, Dde I, Ase I, Hin f I, Alu I, Hin c II, Dpn I and Eco R V. Each amplicon was treated with 1.0 U of restriction enzyme and incubated 12-16 hours at 35°C. For easy comparisons among individual lizards, digestions of all lizards within an enzyme were loaded onto a 1.0% (w/v) midi agarose gel. Different restriction patterns were coded as different haplotypes and scored for each individual.

Binary character matrices included only restriction sites (Hillis 1996) from those enzymes that yielded more than one haplotype from all individuals treated. The presence or absence of each restriction site (from enzymes that yielded more than one haplotype for all individuals sampled) were used as discrete characters in the matrices (Georgiadis 1996). Phylogenetic trees were generated by PHYLIP® (Felsenstein 1993). The documentation information with this software package was
used to determine which analysis should be used. The Wagner and Dollo parsimony approaches appeared to be the most relevant to binary data sets (Felsenstein 1993). The Wagner parsimony program was chosen over Dollo parsimony because of its allowance for the equal probability that a mutation event will either create or destroy a restriction site. The Dollo program assumes that restriction sites are more likely to be destroyed than created by mutation events. It is the opinion of the authors of this study that this assumption cannot be supported without sequencing the PCR fragment. The more liberal view of mutation event ramifications upheld by the Wagner parsimony program, therefore, appeared more appropriate for this analysis.

Bootstrapping (Felsenstein 1985) was performed 100 times on these data. In the program used (PARS), the most parsimonious representation for the data is found. Bifurcations and multifurcations in trees are considered, and numerical trees are produced (Felsenstein, 1993). The tree-drawing program produces a graphical illustration of the most parsimonious numerical tree.

**RESULTS**

Five (*Cfo* I, *Sau* 96 I, *Hpa* II, *Hin f* I and *Alu* I) of the 12 restriction endonucleases cleaved the amplicons with more than one haplotype. From these five enzymes, 19 restriction sites were gleaned (Table 1). When considering only the restriction enzymes that cleaved the PCR amplicon with more than one haplotype, only Haplotype 2 from *Hin f* I appears to be unique to a single collection site. This haplotype was found in five of the six (83%) individuals captured at the O. C. Fisher Lake. The 12 remaining haplotypes from these five enzymes were shared between individuals of at least two sites. The bootstrapped gene tree (Fig. 1) generated from the restriction site data demonstrated genetic trends among the populations. Much of this tree was supported by bootstrap values of more than 60%. However, some sections of the tree were inferred with values less than 40%. Since much of the tree has a high probability of accuracy, population structure can be inferred.

Both individuals from E. V. Spence Reservoir were placed together. This bootstrap value was high (74%) and is likely accurate. Five of the six lizards captured at O. C. Fisher Lake were placed on a single branch, as well. The likelihood of this arrangement was calculated at 90%. The other individual captured from this site was placed on a low-probability branch (≈ 40%) with lizards from Ballinger Municipal Lake, Twin Buttes Reservoir and the Sims Ranch.
In contrast, *Crotaphytus collaris* individuals \((n=4)\) captured from Twin Buttes Reservoir did not place in well-supported branches on the gene tree. One lizard was placed on the branch shared with the majority of the O. C. Fisher Lake lizards. The bootstrap value generated for this arrangement was calculated at 70\% and is likely accurate. However, the other three lizards were placed on a branch of the tree that bootstrapped at approximately 40\%. This positioned these three individuals with members of the Ballinger, Sims and O. C. Fisher populations.
This was also the case for members of the Ballinger Municipal Lake sample \((n=4)\). One of these lizards was placed on a branch of 63% probability with two Carter Ranch individuals. The remaining three lizards were positioned on a low probability branch with members of the Twin Buttes, Sims and O. C. Fisher samples.
The lizards captured from the Carter Ranch ($n=6$) were among the most dispersed on the gene tree. Two individuals were placed with the two lizards captured at E. V. Spence Reservoir with a probability of 74%. Two more Carter Ranch lizards were placed with a single lizard from the Ballinger sample site with a bootstrap of 63%. The last two Carter Ranch lizards were arranged with 10 lizards from the Sims Ranch. The bootstrap value of this arrangement was lower than 40%.

When the gene tree is applied to maps of the collection sites, inter-populational data can be inferred. If all of the tree is applied to the map of the collection sites (Fig. 2), it is obvious that gene flow is occurring between E. V. Spence and the Carter Ranch. In fact, this appears to be the only gene flow to or from E. V. Spence Reservoir. Ballinger Municipal Lake is linked both to the Carter Ranch and to the Sims Ranch. In addition, gene flow to and from O. C. Fisher appears to be linked mainly to Twin Buttes. The Carter Ranch appears to be linked to Ballinger Municipal Lake and E. V. Spence. The Sims Ranch appears to be linked to all collection sites except E. V. Spence.
The gene tree applied to the geographic locations was also informative when only the most strongly supported clades (>60% bootstrap values) were analyzed (Fig. 3). Again, only the Carter Ranch is connected to the E. V. Spence lizards. The Carter Ranch is clearly linked to Ballinger Municipal Lake. Also, Twin Buttes and O. C. Fisher individuals appear linked. The branch with five of the six O. C. Fisher lizards and a single Twin Buttes lizard also appears. The Sims Ranch has no well-supported gene flow affiliations with any other population when analyzed with this method.

**DISCUSSION**

It is likely that many of the 12 restriction endonucleases utilized did not yield differing haplotypes because these areas of the amplicon are highly conserved. Mutations at these sites possibly result in lethal changes in protein structure. Mutations can and will occur at these sites, but individuals are not viable and do not reproduce. For this reason, haplotypes arising from mutations at these sites are not observed in the populations sampled. However, it is possible that mutations at these restriction sites occur at low rates in viable individuals but were not observed due to an insufficient sample size.

Because *Crotaphytyus collaris* individuals captured on the Carter Ranch grouped with individuals from all other populations, one can infer that this site contains all ancestral haplotypes at these restriction sites, relative to the sites sampled. Even though individuals captured at the Sims Ranch did not link to any members of the E. V. Spence population, and all branches containing Sims Ranch lizards were poorly supported, one could infer that the Sims Ranch individuals also contained all ancestral haplotypes for these restriction sites.

When considering the gene tree (Figure 1), only the lizards from E. V. Spence Reservoir form an exclusive group. This group is tied only to the Carter Ranch on a high-probability branch. This indicates strong gene flow between these two populations. An individual captured at the Ballinger Municipal Lake is tied to two Carter Ranch individuals. Other Ballinger Lake individuals are grouped with lizards from Twin Buttes, O. C. Fisher and Sims Ranch. This suggests genetic flow to Ballinger Lake from all of these sources. It is also to be noted that the Carter Ranch is tied to all other collection sites sampled, and the Sims Ranch is tied to all other sample sites except E. V. Spence. One possible explanation for this is that the Carter and Sims Ranches are ancestral to
Figure 3. Well-supported gene tree branches applied to a geographical map of the collection sites. The branches used are of a 60% or higher bootstrap value.

all other populations sampled. Because of this, the other populations contain subsets of ancestral diversity.

The ages of the sites also shed light on the apparent gene flow observed. The Carter and Sims Ranches are the oldest of the sites in this study. Because of this, the strong gene flow apparent between them in Figure 2 is expected. It is possible that both of these populations were founded from the same parent population, and gene exchange has been occurring for many years. The fact that gene flow is occurring between the older ranch populations and the newer lake populations is logical. As the new habitats were founded, the routes of gene flow extended.

The most convincing argument for the gene flow observed in this study is illustrated in Figure 3. Clear and logical paths of genetic exchange are visible when the most poorly supported branches of the gene tree are removed from the map of the collection sites. In this representation, the Sims Ranch is left unlinked to any other population sampled. This can be explained again by its age. Its ties to the Carter
Ranch are likely a result of a common founder population. All links to lizards from Twin Buttes, O. C. Fisher and Ballinger Municipal Lake are likely carried over indirectly from the Carter Ranch exchanges. No gene flow is extended from the Sims Ranch to any of the populations directly, but similarities are observed due to a possible common ancestral population. Sufficient diversity existed within these 19 restriction sites in the Sims Ranch lizards to allow the tree-drawing algorithm of PHYLIP® to group them with the lizards of virtually all other populations.

The gene flow paths from the Carter Ranch are likely more accurate in Fig. 3 than Fig. 2. When the poorly supported branches are removed, it is obvious that the Carter Ranch is linked to E. V. Spence and Ballinger Municipal Lake. E. V. Spence is linked only to the Carter Ranch. O. C. Fisher and Twin Buttes also engage in genetic exchange. Also, the Carter Ranch is the only well-supported genetic link to the Ballinger Municipal Lake (Figure 1).

Age of habitat again becomes significant when applied to Figure 3. O. C. Fisher Lake was completed in 1951, and probably was colonized by populations receiving gene flow from the Carter Ranch. Subsequently, Twin Buttes Reservoir was completed in 1963. It appears that gene flow extended from the population established 14 years earlier at O. C. Fisher Lake since Twin Buttes lizards do not group with high probability to any lizards from the Carter Ranch. This is expected when the close proximity of O. C. Fisher to Twin Buttes is considered. The Carter Ranch also appears to have extended its gene flow to E. V. Spence Reservoir upon its completion in 1969. It is unlikely that the same geographic path was taken from the Carter Ranch to both O. C. Fisher and to E. V. Spence since lizards from each location do not form a branch of high probability on a gene tree. The same appears to be true of the geographic path of gene flow between the Carter Ranch and Ballinger Municipal Lake. This lake was completed in 1984, but no individuals from either O. C. Fisher or E. V. Spence form high probability branches with those of Ballinger Municipal Lake.

It does not appear possible that this hypothetical path extends in a roughly northward direction from the Carter Ranch and trifurcates, turning toward these three lake sites. Lizards from each of these three populations would be placed on separate branches on a gene tree, and each of these branches would contain lizards from the Carter Ranch.
However, only Ballinger Municipal Lake and E. V. Spence form branches with Carter Ranch individuals. This indicates that the population of *Crotaphytus collaris* at O. C. Fisher Lake has diverged to a greater extent from the Carter Ranch than the populations at E. V. Spence and Ballinger Municipal Lake. Again, this could be an artifact of its age, relative to the other sites. It is possible that a geographic boundary has severed gene flow between this population and the one at the Carter Ranch. The resulting isolation could cause this divergence. However, extensive geographic knowledge and the exact position of all satellite populations of *C. collaris* would be necessary to reach this conclusion. An isolation theory is applicable to the Sims Ranch population, as well. It is closer to Ballinger Municipal Lake than is the Carter Ranch, but branches linking Ballinger Municipal Lake to the Sims Ranch were of a low probability. Again, extensive geographical knowledge would be needed to support this theory.

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LITERATURE CITED


Mitochondrial DNA variation in chinook (Oncorhynchus tshawytscha) and chum salmon (O. keta) detected by restriction enzyme analysis of polymerase chain reaction (PCR) products. Canadian Journal of Fisheries and Aquatic Science, 50:708-715.


JHC at: jim_h_campbell@yahoo.com
EVALUATION OF FACILITATED SUCCESSION 
AT LAS PALOMAS WILDLIFE MANAGEMENT AREA 
IN SOUTH TEXAS 

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Abstract.—This study examined the effectiveness of re-vegetation efforts which have been ongoing in the Lower Rio Grande Valley of Texas since 1958. Species composition, richness and diversity were evaluated in an undisturbed native woodland, a site planted with late successional species in 1961 (facilitated succession) and a farm field abandoned in 1974 (unaided succession) in northwestern Cameron County. Species richness and diversity for both trees and shrubs were greatest in the native woodland site. While there was greater similarity in species composition between the native woodland and the facilitated succession sites, species diversity in the tree and shrub layers of the facilitated succession site is still significantly lower than the native woodland site.

The Lower Rio Grande Valley (LRGV) of Texas is both a political and a biogeographic unit. As a political unit it comprises the southernmost four counties in Texas, i.e., Cameron, Hidalgo, Starr and Willacy. Biogeographically, it corresponds closely with the Matamoran District of the Tamaulipan Biotic Province (Blair 1950). It includes all of the Pleistocene-Recent delta of the Rio Grande in Texas. This 1,208,530 ha area exhibits great biodiversity. More than 500 vertebrate and 170 woody species occur in the LRGV. Sixty-seven species are considered threatened or endangered (Jahrsdoerfer & Leslie 1988). Because of its high biodiversity, large number of threatened and endangered species, large number of neotropical species that reach the northern limit of their distribution in the area, and small amount of native habitat remaining, the Texas and U.S.A. governments are combining to purchase lands for preservation and re-vegetation.

The U. S. Fish and Wildlife Service (USFWS) Land Protection Plan calls for protection of 53,420 ha in the LRGV using island biogeography concepts (Harris 1984) with the Rio Grande serving as the major corridor linking tracts of native and restored vegetation. When completed, the Lower Rio Grande Wildlife Corridor will extend 240 km
from the mouth of the river in Cameron County to Falcon Dam in Starr County. Lands acquired by USFWS for the corridor become a part of the Lower Rio Grande Valley National Wildlife Refuge. It currently consists of over 100 tracts comprising about 26,000 ha. To date about 2,430 ha have been re-vegetated.

Since 1958, Texas Parks and Wildlife Department (TPWD) has been involved in re-vegetation in the LRGV to create white-winged dove (Zenaida asiatica) habitat and to promote biodiversity. TPWD has planted about 260 ha on 12 tracts. The Texas Nature Conservancy (TNC) also has promoted re-vegetation efforts, primarily by encouraging and helping private land owners to plant native woody species. This has culminated in the re-vegetation of 27 tracts comprising 364 ha. The combined efforts of the USFWS, TPWD, and TNC have resulted in the re-vegetation of about 3,054 ha.

The lands acquired to create white-winged dove habitat and promote biodiversity are usually recently cultivated fields. Left alone these abandoned fields undergo secondary succession. The first plants to become established typically are herbaceous annuals (Vora & Messerly 1990). In time, these colonizing species are gradually replaced by woody species. The rate at which succession occurs depends, in part, on the ability of mid and late successional species to disperse to a site and successfully compete with colonizing species that are already established. Re-vegetation projects attempt to accelerate succession by introducing climax species into an area. Thus, these re-vegetation efforts are based on the Facilitation Model of succession (Connell & Slayter 1977). Vora & Messerly (1990) suggested that unaided succession in LRGV communities fit the Facilitation Model and Archer et al. (1988) reported that succession at a site 175 km north of the Rio Grande fit the Facilitation Model.

Re-vegetation efforts in the LRGV have been ongoing since 1958 and have occurred annually since 1983. However, there has been no assessment of the effectiveness of these re-vegetation efforts in accelerating succession or in achieving similar composition and structure as existing climax communities. Only one study (Vora & Messerly 1990) provides information on succession in the LRGV, and it covers only a five-year time period. Consequently this study sought information on the effectiveness of facilitated succession in achieving similar composition, structure, and diversity, in a period of 40 years, to an undisturbed forest at the TPWD’s Longoria Unit of the Las Palomas Wildlife Management Area (LPWMA) in northwestern Cameron County.
METHODS

The Longoria Unit is a 80.9 ha public hunting site located 7.4 km north of Santa Rosa, Cameron County, Texas (Fig. 1). Soils at the site belong to the Raymondville Association, which are characterized by nearly level, moderately drained, clay loams (Williams et al. 1977). The climate is semi-arid and annual precipitation is about 68 cm with a rainfall peak in September and October (Lonard et al. 1991). The mean frost-free period is 330 days. Frequently an entire winter will pass without a freezing temperature.

Controls were not established when the re-vegetation was done so this study compared vegetation at three sites: (1) an undisturbed woodland, (2) a re-vegetated site and (3) an unaided secondary succession site. Historically, the Longoria Unit was a small portion of a Spanish land grant. The former owner of the tract indicated that the site selected as undisturbed woodland had never been cleared for agriculture or grazing. The facilitated succession site was formerly a cultivated field that was
re-vegetated in 1961. Seedlings of anacua (*Ehretia anacua*), brasil (*Condalia hookeri*), Texas ebony (*Chloroleucon ebano*) and granjeno (*Celtis pallida*) were hand-dug and planted in rows 3.0 m apart. Plants within rows were spaced 2.4 m apart and approximately equal numbers of each of the species were planted. Seedlings were watered, fertilized, and hand-pruned to enhance branching for white-winged dove nests. Successful nesting first occurred seven years after planting. The unaided succession site was a cultivated field that was abandoned in 1958. It was mowed infrequently from 1958 to 1974. In 1974 all mechanical plant control operations ceased and the area was allowed to undergo secondary succession. Thus, except for the ground layer it had been in succession for 13 fewer years than the facilitated succession site. The sites are all close to each other and separated by dirt roads about 5 m wide.

To census the vegetation, ten 10 m by 10 m quadrats were established at regular intervals of 150 m along a north/south axis across each of the three sites. Censusing of tree, shrub and ground layers was done separately. The tree layer consisted of woody plants greater than 3.0 m tall. The shrub layer was comprised of woody plants 1.0 to 3.0 m tall. The ground layer consisted of woody and herbaceous plants less than 1.0 m tall. Heights were determined with a calibrated telescoping pole. Density of trees and shrubs was counts of individuals in the quadrats. Frequency was determined by the presence of a species in the 10 quadrats at a site. Cover was based on diameter at breast/height (dbh = 1.35 m) of trees and basal diameter of shrubs. Multiple stems were summed. Dominance in the tree and shrub layers was determined by calculating an importance value, which was the sum of relative density, relative frequency, and relative cover. Heights of trees and shrubs were determined using a calibrated telescoping pole that had a maximum height of 7.5 m. Height of trees taller than 7.5 m was estimated. The ground layer was censused using the line intercept technique (Canfield 1941). Five 10 m long intervals were established spaced 2 m apart across each quadrat. Thus, at each site there were 50 intervals. Cover was determined by the perpendicular projection of the foliage onto the transect line. Frequency was based on the presence of a species in the 50 intervals of the transects. To determine the density of tree and shrub seedlings, a 10 cm strip on each side of the transect was established. Density and height of tree and shrub seedlings less than 1 m tall were determined in the 20 cm wide belts. For all other ground layer species, density was not determined because of the difficulty in identifying what
constituted an individual. Dominance was assessed in the ground layer by calculating an importance value that was the sum of relative frequency and relative cover.

Similarity of floristic composition within layers among sites was determined using Sorenson's coefficient of community (Krebs 1999). Species diversity and evenness was assessed using the Shannon-Wiener function applied to species importance values (Brower et al. 1998; Krebs 1999). Tests for significant differences follow information in Sokal & Rohlf (1981). Nomenclature follows Jones et al. (1997).

**RESULTS**

Species presence, richness, mean height and importance in the tree layer are compared among sites in Table 1. The native woodland had the greatest number of species (13). All four of the species (*Ehretia anacua, Celtis pallida, Condalia hookeri* and *Chloroleucon ebano*) initially planted at the facilitated succession site were present in the native woodland. *Ehretia anacua* (anacua) was the dominant species in the tree layer at this site. *Condalia hookeri* (brasil) was a close second in importance. *Prosopis glandulosa* (mesquite), *Celtis laevigata* (hackberry) and *Chloroleucon ebano* (Texas ebony) were the tallest trees, but density of mesquite and Texas ebony was low. Similarly, all four of the species initially planted at the facilitated succession site were present here (Table 1). Only three tree species were added to the facilitated succession site in the 40 years since planting, and species richness was just seven (54% of the native woodland). Anacua also was the dominant species in the tree layer at this site. Mean height of anacua was similar to the height of the species in the native woodland. Indeed, except for Texas ebony, the heights of other species in the tree layer of the facilitated succession were similar to their counterparts in the native woodland. The unaided succession site (Table 1) had one more species in the tree layer (8) than the facilitated succession site. All four species initially planted at the facilitated succession site were present in the tree layer. *Zanthoxylum fagara* (colima) was the dominant species. Anacua was second in importance. Except for *Celtis pallida* (granjeno), mean height of the trees was shorter than their counterparts in the native woodland.

Species presence, richness and importance in the shrub layer of the sites are shown in Table 2. Mean height is not presented because this layer was rather narrowly defined as being between 1.0 and 3.0 m. The
Table 1. Mean height and species importance in the tree layer. Imp. value = importance value and is the sum of relative frequency, relative density and relative cover. Density is number per 1,000 sq. m.

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<th>Species</th>
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<th>Freq. (%)</th>
<th>Rel. Freq.</th>
<th>Den. (Freq.)</th>
<th>Rel. Den.</th>
<th>Cover (cm)</th>
<th>Rel. Cov.</th>
<th>Imp. Value</th>
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native woodland had the greatest number of species (16) and the unaided succession and facilitated succession sites had equal numbers of species (12). Three of the four species initially planted in the facilitated succession site were present in all three sites (anacua, Texas ebony and granjeno), but brasil was present as a shrub only in the native woodland site (Table 2). *Forestiera angustifolia* (panalero) was the dominant shrub at the native woodland. Anacua was the dominant species in the shrub layer at the facilitated succession site and colima was the dominant...
Table 2. Species importance in the shrub layer. Imp. value = importance value and is the sum of relative frequency, relative density and relative cover. Density is number per 1,000 sq. m.

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<td>11.5</td>
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<tr>
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<tr>
<td>Forestiera angustifolia</td>
<td>70</td>
<td>10.3</td>
<td>12</td>
<td>4.4</td>
<td>19.5</td>
<td>4.9</td>
<td>19.6</td>
</tr>
<tr>
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<td>70</td>
<td>10.3</td>
<td>14</td>
<td>5.1</td>
<td>4.4</td>
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<td>16.5</td>
</tr>
<tr>
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<td>50</td>
<td>7.4</td>
<td>8</td>
<td>2.9</td>
<td>7.0</td>
<td>1.7</td>
<td>12.0</td>
</tr>
<tr>
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<td>4.4</td>
<td>6</td>
<td>2.2</td>
<td>12.3</td>
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<td>9.7</td>
</tr>
<tr>
<td>Malpighia glabra</td>
<td>10</td>
<td>1.5</td>
<td>1</td>
<td>0.4</td>
<td>1.0</td>
<td>0.2</td>
<td>2.1</td>
</tr>
<tr>
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<td>1.5</td>
<td>1</td>
<td>0.4</td>
<td>0.5</td>
<td>0.1</td>
<td>2.0</td>
</tr>
<tr>
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<td>0.4</td>
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<td><strong>Unaided Succession Site</strong></td>
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<td></td>
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<td></td>
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<td>15.0</td>
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<td>31</td>
<td>12.1</td>
<td>112.5</td>
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<td>7.0</td>
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<tr>
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<td>8.3</td>
<td>6</td>
<td>2.3</td>
<td>16.4</td>
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<td>21.4</td>
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<td>7.4</td>
</tr>
<tr>
<td>Randia rhagocarpa</td>
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<td>3</td>
<td>1.2</td>
<td>10.4</td>
<td>1.4</td>
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<td>3.3</td>
<td>3</td>
<td>1.2</td>
<td>7.9</td>
<td>1.1</td>
<td>5.6</td>
</tr>
<tr>
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<td>0.8</td>
<td>1.4</td>
<td>0.2</td>
<td>4.3</td>
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<tr>
<td><strong>Total number of plants = 257</strong></td>
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</table>
Table 3. Species importance in the ground layer. Imp. value = importance value and is the sum of relative frequency and relative cover.

<table>
<thead>
<tr>
<th>Species</th>
<th>Freq. (%)</th>
<th>Rel. Freq.</th>
<th>Cover (%)</th>
<th>Rel. Cover</th>
<th>Imp. Value</th>
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<tbody>
<tr>
<td></td>
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<td></td>
</tr>
<tr>
<td>Undisturbed Woodland</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Rivina humilus</td>
<td>92</td>
<td>13.6</td>
<td>8.67</td>
<td>32.8</td>
<td>46.4</td>
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<tr>
<td>Chromolaena odorata</td>
<td>64</td>
<td>9.5</td>
<td>5.90</td>
<td>22.3</td>
<td>31.8</td>
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<tr>
<td>Cocculus diversifolius</td>
<td>90</td>
<td>13.3</td>
<td>1.11</td>
<td>4.2</td>
<td>17.5</td>
</tr>
<tr>
<td>Trixis inula</td>
<td>42</td>
<td>6.2</td>
<td>2.88</td>
<td>10.9</td>
<td>17.1</td>
</tr>
<tr>
<td>Tamaulipia azurea</td>
<td>44</td>
<td>6.5</td>
<td>2.49</td>
<td>9.4</td>
<td>15.9</td>
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<tr>
<td>Forestiera angustifolia</td>
<td>40</td>
<td>5.9</td>
<td>0.69</td>
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<td>8.5</td>
</tr>
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<td>Malpighia glabra</td>
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<td>2.4</td>
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<td>7.6</td>
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<tr>
<td>Salvia coccinea</td>
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<td>0.37</td>
<td>1.4</td>
<td>6.7</td>
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<td>0.21</td>
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<tr>
<td>Clematis drummondii</td>
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<td>2.7</td>
<td>0.39</td>
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<td>4.2</td>
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<tr>
<td>19 additional species</td>
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<tr>
<td>Total cover = 26.47%</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Unaided Succession Site</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
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<td>Chromolaena odorata</td>
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<td>27.0</td>
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<td>11.2</td>
<td>8.94</td>
<td>25.1</td>
<td>36.3</td>
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<td>25.0</td>
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<td>7.9</td>
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<td>0.47</td>
<td>1.4</td>
<td>7.3</td>
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<td>6.5</td>
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<td>5.7</td>
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<td>1.12</td>
<td>3.3</td>
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<tr>
<td>Ehretia anacua</td>
<td>30</td>
<td>3.6</td>
<td>0.42</td>
<td>1.2</td>
<td>4.8</td>
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<tr>
<td>24 additional species</td>
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<tr>
<td>Total cover = 33.87%</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Facilitated Succession Site</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rivina humilus</td>
<td>100</td>
<td>15.4</td>
<td>4.39</td>
<td>26.5</td>
<td>41.9</td>
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<td>11.7</td>
<td>4.45</td>
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<td>38.5</td>
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<tr>
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<td>54</td>
<td>8.3</td>
<td>2.12</td>
<td>12.8</td>
<td>21.1</td>
</tr>
<tr>
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<td>48</td>
<td>7.4</td>
<td>1.83</td>
<td>11.0</td>
<td>18.4</td>
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<td>0.85</td>
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<td>0.53</td>
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<td>42</td>
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<td>0.29</td>
<td>1.7</td>
<td>8.2</td>
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<td>0.52</td>
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<td>8.0</td>
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<tr>
<td>Zanthoxylum fagara</td>
<td>27</td>
<td>4.2</td>
<td>0.17</td>
<td>1.0</td>
<td>5.2</td>
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<td>Celtis pallida</td>
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<td>3.7</td>
<td>0.10</td>
<td>0.6</td>
<td>4.3</td>
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<td>Matelea reticulata</td>
<td>22</td>
<td>3.4</td>
<td>0.15</td>
<td>0.9</td>
<td>4.3</td>
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<tr>
<td>Serjania brachycarpa</td>
<td>18</td>
<td>2.8</td>
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<td>3.8</td>
</tr>
<tr>
<td>18 additional species</td>
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<td></td>
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<tr>
<td>Total cover = 16.58%</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

in the shrub layer at the unaided succession site. *Baccharis neglecta* (jara dulce), a well known successional stage species, was third in
importance at this site. The unaided succession was the only one of the three sites to support jara dulce.

Species presence, richness and importance in the ground layer are compared among sites in Table 3. The unaided succession site had the greatest number of species (36) and the native woodland and facilitated succession sites had equal numbers of species (31). Only the unaided succession site had all four of the species initially planted at the facilitated succession site present in the ground layer. Texas ebony was absent in the ground layer of the native woodland and brasil was absent in the ground layer at the facilitated succession. *Rivina humilus* (coralito) was the dominant species in the ground layer at the native woodland and facilitated succession, but *Chromolaena odorata* (crucita) was dominant at the unaided succession. Eleven of the 13 species present in the tree layer of the native woodland were present in the ground layer at this site, which suggests that the tree species are being perpetuated. Ten of the 13 species present in the tree layer of the native woodland were present in the ground layer of the unaided succession site. Ten is two species more than are currently present in the tree layer at the unaided succession site, and it suggests that the species richness and diversity in the tree layer here may improve in the future. Similarly, 10 of the 13 species present in the tree layer of the native woodland site were present in the ground layer of the facilitated succession. This is three more species than are currently present in the tree layer at the site. Again, this suggests that species richness and diversity of the tree layer at the facilitated succession site may improve in the future.

Nine (facilitated succession) to 10 (native woodland and unaided succession) of the tree species also were represented in the shrub stage. Only three species (*Acacia greggii, Havardia pallens* and *Prosopis glandulosa*) were not present in the shrub stage. *Acacia greggii* and *H. pallens* were each represented by a single individual in the quadrats. *Prosopis glandulosa* was represented by two individuals.

Table 4 shows a comparison of coefficients of similarity among layers and sites. There was greater similarity in species in the tree and shrub layers between the native woodland and the facilitated succession than there was between the native woodland and the unaided succession. Conversely, similarity in the ground layer was greater between the native woodland and the unaided succession. The two successional sites were more similar to each other in the tree layer and ground layer than either was to the native forest.
Table 4. Comparison of coefficients of similarity among layers and treatments.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Tree Layer</th>
<th>Shrub Layer</th>
<th>Ground Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undisturbed Woodland and Unaided Succession</td>
<td>.571</td>
<td>.714</td>
<td>.746</td>
</tr>
<tr>
<td>Undisturbed Woodland and Facilitated Succession</td>
<td>.700</td>
<td>.857</td>
<td>.716</td>
</tr>
<tr>
<td>Unaided Succession and Facilitated Succession</td>
<td>.800</td>
<td>.750</td>
<td>.774</td>
</tr>
</tbody>
</table>

Table 5 shows a comparison of species richness, evenness, species diversity and variance of the species diversity among sites and vegetation layers. Table 6 shows the *t*-values, degrees of freedom and probabilities for comparisons between sites within layers. Evenness was greater than .75 in all cases and was relatively similar among sites within a layer. Generally, evenness was inversely related to species richness among the layers with evenness being highest for the tree layer and lowest for the ground layer. Species diversity was greater in the ground layer because of the greater species richness there. Within the tree layer, species diversity was significantly greater in the undisturbed woodland than in either of the succession sites (Tables 5 & 6). In the shrub layer, species diversity in the undisturbed woodland was significantly greater than in the facilitated succession site. There were no significant differences in species diversity among sites in the ground layer.

**DISCUSSION**

Mesquite is often depicted as a dominant species in the South Texas Plains (e.g. Kuchler 1964). Clearly, this is not consistently the case in the Lower Rio Grande Valley. This study provides the first quantification of importance of all species comprising a thorn woodland community in the Lower Rio Grande Valley of Texas. It shows that the dominant tree species in the native woodland is anacua and that mesquite is scarce at this locality. Mesquite is the tallest of the trees, however, and this might tend to make it conspicuous even if less abundant than other species.

Vora (1990) gives a canopy cover value for the dominant species (mesquite) in a woodland community at a site 5 km west of Mission,
Table 5. Comparison of species richness (Sp), evenness ($J^1$), species diversity ($H^1$) and variance ($s^2$) of the species diversity index among treatments and vegetation layers.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Undisturbed Woodland</th>
<th>Unaided Secondary Succession</th>
<th>Facilitated Succession</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sp</td>
<td>$J^1$</td>
<td>$H^1$</td>
</tr>
<tr>
<td>Tree</td>
<td>13</td>
<td>.892</td>
<td>.944</td>
</tr>
<tr>
<td>Shrub</td>
<td>16</td>
<td>.843</td>
<td>1.016</td>
</tr>
</tbody>
</table>

Hidalgo County, Texas, but he does not provide a measure of abundance for other species in the community. He stated that the overall density of overstory trees was 250 to 380 per ha. A much higher density of trees of 2,870 per ha was found in this study. The difference may be due, in part, to differences in defining what constituted a tree. A 3.0 m or taller height was used as the criterion in this study. Vora (1990) does not state what criterion he used, but he reports that tree height ranged from 5.3 to 9.6 m. Using a lower limit of tree height of 5.3 m would have markedly reduced the density of trees in this current study.

The facilitation was not done as part of a succession experiment, rather it was done to create white-winged dove nesting habitat quickly. Consequently, there was no contemporaneous unaided control. However, the immediate proximity of the undisturbed native woodland and the subsequent abandonment of adjacent farmland provided a mature woodland control and a non-contemporaneous unaided control site. In 40 years, the facilitated succession has not achieved species richness or species diversity of trees and shrubs equal to that of native woodland. Indeed, the facilitated succession site is no better in species diversity and richness than an unaided succession site that has had only 27 years of succession. However, composition of the facilitated succession is more similar to the native woodland than is the unaided succession. The native woodland and facilitated succession have the same dominant species in the tree and ground layers, while none of the dominants is the same in the native woodland and unaided succession. Thus, based on similarity of dominant species and similarity of all species, there is greater similarity between the native woodland and the facilitated succession in the shrub and tree layers than between the native woodland and unaided succession. Whether this relationship will hold after the unaided succession has had 13 more years for development remains to be seen.
Table 6. Student’s t-tests for comparisons of species diversity between treatments within vegetation layers. $H^1$ and $s^2$ values are given in Table 5.

<table>
<thead>
<tr>
<th>Comparison</th>
<th>$t$</th>
<th>$df$</th>
<th>$P$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tree layer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undisturbed Woodland vs Facilitated Succession</td>
<td>7.120</td>
<td>656</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Undisturbed Woodland vs Unaided Succession</td>
<td>8.400</td>
<td>592</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Facilitated Succession vs Unaided Succession</td>
<td>2.000</td>
<td>599</td>
<td>&lt; .05</td>
</tr>
<tr>
<td><strong>Shrub layer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undisturbed Woodland vs Facilitated Succession</td>
<td>5.000</td>
<td>583</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Undisturbed Woodland vs Unaided Succession</td>
<td>1.486</td>
<td>399</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Facilitated Succession vs Unaided Succession</td>
<td>1.821</td>
<td>399</td>
<td>&gt; .05</td>
</tr>
<tr>
<td><strong>Ground layer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Undisturbed Woodland vs Facilitated Succession</td>
<td>1.563</td>
<td>400</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Undisturbed Woodland vs Unaided Succession</td>
<td>.021</td>
<td>400</td>
<td>&gt; .05</td>
</tr>
<tr>
<td>Facilitated Succession vs Unaided Succession</td>
<td>.054</td>
<td>400</td>
<td>&gt; .05</td>
</tr>
</tbody>
</table>

Vora (1990) reported jara dulce, buffelgrass and bermudagrass were dominant species after five years in an old-field succession near Mission, Texas. Jara dulce was third in importance in the tree layer of the unaided succession, but was not present in the facilitated succession or the native woodland. Thus, it appears that jara dulce is eliminated from the woodland succession between 27 and 40 years after initiation of the succession.

Clearly, the unaided succession site has not reached the composition or structure of the native woodland in 27 years. And, while the facili-
tated succession site has reached a composition and structure similar to that of native woodland it lacks the diversity provided by scarce to rare species that is present in the native woodland. Three lines of evidence suggest that the unaided succession site is still undergoing succession. First, jara dulce is present and it is known to be a successional stage that appears within five years and then does not persist into mature communities (Vora 1990). Second, all but one of the species present in the tree layer were shorter than their counterparts in the native woodland. Third, anacua was second in importance rather than the dominant as it was in the native woodland.

It is thought that establishing tree and shrub cover on newly acquired agricultural fields will provide perches for birds, which will bring in seeds of many additional species (Vora 1992). At a locality 175 km north of the Rio Grande near Alice, Jim Wells County, Texas, Archer et al. (1988) demonstrated that mesquite trees serve as such foci for bird disseminated seeds of other woody species. The resulting tree and shrub clusters eventually coalesce to form closed canopy woodlands (Archer 1989; 1990). In the facilitated succession, three species have been added to the tree layer: hackberry, *Ulmus crassifolia* (cedar elm) and colima. Colima and hackberry have become more abundant than any of the species originally planted except for anacua. Another six species of shrubs have been added to the facilitated succession. Based on data provided by Van Auken & Bush (1985) for a community on a terrace of the San Antonio River about 380 km north of LPWMA, it might take up to 150 years for a woodland community to reach maturity. However, the dominant species of mature communities there appear to reach dominance in about 30 years. Clearly, anacua has achieved dominace in the facilitated succession at LPWMA in 40 years. However, in the unaided succession it is second in importance. Therefore, these data suggest that dominance by anacua may be expected to occur between 27 and 40 years. Additional data points are needed to ascertain the developmental rate of the woodland succession with respect to species richness and diversity.

Acknowledgments

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Abstract.—The issue of a minimum flow threshold (also referred to as enable level) above which to trigger sampling plays an important role in water quality sampling projects; however, guidance on developing appropriate storm sampling strategies for small streams is limited. As a result, arbitrary strategies are used that may not accurately characterize pollutant flux. Therefore, the objectives of this study were to: (1) compare measured nutrient flux data to hypothetical results collected under several alternative minimum flow threshold or enable level scenarios and (2) publish initial guidance on setting minimum flow thresholds for automated storm sampling in small watersheds. Comparison of measured nutrient fluxes for various enable level scenarios illustrated that substantial error is introduced even with relatively small enable level increases. Based on these results, minimum flow thresholds for automated sampling equipment should be set such that even small storms with small increases in flow depth are sampled. In order to manage the number of samples collected, enable levels should be raised only after careful consideration of the resulting consequences. Alternatives for decreasing the number of samples in nutrient flux measurements, such as increasing the time or flow volume between samples or compositing several samples into one collection bottle, introduce substantially less error than does increasing minimum flow thresholds.

Monitoring water quality during storm events is becoming increasingly important in characterization of pollutant loading to water bodies, especially as National Water Quality Inventories (USEPA 1995; USEPA 2000) continue to report that nonpoint source (NPS) pollution adversely impacts rivers, lakes and coastal waters. NPS pollution includes runoff from diffuse sources such as urban areas, farms, and silvicultural operations. Excessive anthropogenic NPS inputs of the macro-nutrients, nitrogen (N) and phosphorus (P) or "cultural eutrophication" can create accelerated algal growth which degrades aquatic ecosystem health, increases water treatment costs and diminishes recreational and aesthetic values (Kolbe & Luedke 1993).

The traditional monitoring focus on periodic grab sampling of low flows to characterize point source pollution (discharged from specific locations such as factories and waste water treatment plants) is now often coupled with automated storm flow monitoring to characterize NPS
pollution. Most commercially available automated samplers contain similar components, including: programmable operation and memory, water level recorder, sample collection pump and sample bottles. Typical storm sampling operation involves setting a minimum flow threshold or enable level to start and finish sampling (either a flow depth or a rainfall depth per specified time) and setting a time or flow interval on which to collect samples after the sampler is triggered. This type of automated storm monitoring is often the cornerstone of small watersheds projects whose objectives are to compare water quality impacts of various land management activities, evaluate water quality improvement following implementation of best management practices and determine annual pollutant fluxes for Total Maximum Daily Load (TMDL) projects (Tate et al. 1999; Robertson & Roerish 1999).

On small watershed monitoring projects, however, sampling and funding considerations, along with NPS variability, often make it difficult to achieve project objectives (Tate et al. 1999). Budget determination is generally the first step in monitoring projects (Shih et al. 1994). Most sampling proposals specify a maximum number of storms that will be sampled or a maximum number of samples that will be collected, so that a reasonable sampling expectation can be met. Service and maintenance of automated sampling equipment is labor intensive and expensive, and cost considerations often limit the number of samples that can be collected and analyzed (Robertson & Roerish 1999; Dissmeyer 1994). Another consideration in developing a sampling scheme is the number of samples that can be collected and analyzed by a laboratory in a reasonable time frame (Novotny & Olem 1994). Since a large portion of the cost of a monitoring program is directly related to the number of samples, determination of a proper minimum flow threshold and sample frequency is important in achieving objectives within budget limitations. A high minimum flow threshold and/or low frequency sampling bypasses important information and may lengthen the project duration (Novotny & Olem 1994; Shih et al. 1994). However, a low minimum flow threshold and/or high frequency sampling may be inhibited by available financial and laboratory resources.

Guidance on developing storm sampling strategies for small streams is limited, but examples for larger perennial streams and rivers are presented by Robertson & Roerish (1999). The United States Geological Survey NPS program in Wisconsin collects 100 to 200 fixed interval
grab samples and storm flow samples per year for small streams (watersheds less than 100 km²). The typical National Water Quality Assessment strategy collects monthly samples supplemented by four to eight storm samples per year for about 2.5 yr. For larger streams and rivers, precision and accuracy increase with sampling frequency in almost all cases. In smaller watersheds, which are typically more variable in their response than larger ones, more intensive sampling is generally needed to achieve precise and accurate load estimates (Richards & Holloway 1987).

Comparisons of specific automated sampling alternatives are also limited. However, issues of discrete (one sample per bottle) versus composite sampling (several samples per bottle) and flow-weighted (based on flow volume) versus time-weighted sampling (based on time intervals) have been addressed by King & Harmel (2001); Shih et al. (1994); Miller et al. (2000) and others. One important question that has not received attention is what storm size should be sampled, which translates into how many storms are sampled. As stated earlier, this issue of a minimum flow threshold above which to trigger sampling plays an important role in developing sampling strategies. However, without published studies on the impact of setting enable levels, arbitrary decisions are made. General guidance on this issue indicated that for determination of annual storm loads, storms with rain exceeding 25 mm/hr or runoff exceeding 13 mm should be sampled and that generally three to five storms per year create about 75% of the annual runoff (Slade pers. comm.). Tate et al. (1999) state that a majority of annual flow and NPS loading occurs during four to six storms per year on California rangelands. For large rivers, commonly as much as 80% of annual NPS load is contributed by 20% of flows (Richards & Holloway 1987).

Richards & Holloway (1987) indicated that assessment of the adequacy of sampling programs for large rivers is needed. That need also exists for small streams, especially since numerous small watershed monitoring programs are underway with limited assessment of sampling program adequacy. No published guidance is available on setting minimum flow thresholds. If they are set too low, samples will be taken on every runoff event even though no significant NPS load is transported. In this case, analysis cost and personnel time will be wasted. If enable levels are set too high, substantial portions of runoff events and
Table 1. Characteristics of watershed study sites.

<table>
<thead>
<tr>
<th>Area (ha)</th>
<th>Traditional</th>
<th>Precision</th>
<th>Airport</th>
<th>Mixed Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope (1 - 5%)</td>
<td>1 - 5%</td>
<td>1 - 5%</td>
<td>1 - 4%</td>
<td>1 - 8%</td>
</tr>
<tr>
<td>Soil texture</td>
<td>Clay</td>
<td>Clay</td>
<td>70% Impervious, silty clay to sandy clay loam</td>
<td>12% Impervious, silty clay to sandy clay loam</td>
</tr>
<tr>
<td>Landuse</td>
<td>Corn</td>
<td>Corn</td>
<td>Airport</td>
<td>Airport, golf course, residential</td>
</tr>
<tr>
<td>Land management</td>
<td>Conventionally-applied fertilizer, terraces, residue management</td>
<td>Precision applied fertilizer, terraces, residue management</td>
<td>Mowing, limited fertilizer and pesticide use</td>
<td>Mowing, aeration, moderate fertilizer and pesticide use, irrigation</td>
</tr>
<tr>
<td>Flow channel</td>
<td>Ephemeral - grass waterway</td>
<td>Ephemeral - grass waterway</td>
<td>Small perennial stream</td>
<td>Irrigation return flow supplements small perennial stream</td>
</tr>
</tbody>
</table>

possibly entire events will not be sampled, thus valuable information will be missed. Therefore, the objectives of this study were to: (1) compare measured NO$_3$+NO$_2$-N load data to hypothetical load data collected under various enable level scenarios and (2) produce initial guidance on setting minimum flow thresholds for automated storm sampling in small watersheds.

**Materials and Methods**

*Study site description.*—Runoff and water quality data from two nutrient load studies on four watersheds ranging from 5.7 to 66.5 ha in central Texas were used in this analysis (Table 1). Two were agricultural watersheds located 3 km east of Temple, Texas, and two were urban watersheds in Austin, Texas. The Austin/Temple area receives 813 to 889 mm normal annual precipitation, has an average of 273 growing season days per year, and average maximum daily temperatures from 15°C in January to 35°C in August (NOAA 1999).

*Flow measurement and water quality sampling.*—To monitor surface runoff on the agricultural watersheds near Temple, Texas, a 0.61 m H-flume equipped with an ISCO 4230/3700 flow meter and sampler
system was installed at the "outlet" of each field. An ISCO 674 rain gauge and two HOBO rain event recorders were also installed on site to record rainfall data. From February 1999 through January 2001, flow rates were recorded every five minutes during runoff events. Time-weighted, composite samples with four 200 mL samples per bottle were collected automatically during runoff events. Samplers were programmed to sample all runoff events with adequate flow depth to submerge the sampler intake (approximately 38 mm water depth) and allow sample collection. To provide adequate resolution in short duration events and adequate sampling capacity for longer events, samples were taken in five min intervals for 65 min, 15 min intervals for the next 660 min, and 30 min intervals for the final 1200 min.

Similar monitoring strategies were used to measure surface runoff on the urban sites in Austin, Texas. An ISCO 6700 automatic sampler, an ISCO 4150 area velocity flow logger, and an ISCO 674 rain gauge were installed at each site. Two round culverts drain the airport site, and a box culvert drains the mixed urban site. From April 1998 through March 2000, flow rates were recorded every 15 minutes during runoff events. Time-weighted composite samples with six 150 mL samples per bottle were collected automatically during runoff events. As with the agricultural sites, samplers were programmed to sample runoff events with adequate flow depth to submerge the sample intake (38 mm water depth) and allow sample collection. Samples were taken at five min intervals for 120 min, 15 min intervals for the next 720 min, 30 min intervals for the next 1440 min, and 60 min intervals for the next 1440 min.

Samples were collected within 48 hr of runoff events, acidified, iced and transported to the laboratory where they were stored at 4°C prior to analysis. Samples were analyzed for dissolved nitrate plus nitrite nitrogen (NO$_3^-$+NO$_2^-$-N) concentrations using a Technicon Autoanalyzer IIC (Technicon Instruments Corp., Tarrytown, New York) and colorimetric methods published by Technicon Industrial Systems (1973).

For each of the four watersheds, measured dissolved NO$_3^-$+NO$_2^-$-N loads were determined by multiplying measured nutrient concentrations by corresponding flow volumes and summing these incremental loads for the duration of the runoff event. This measured load was then compared to loads that would have been measured for increased enable levels. For
Figure 1. Sample storm illustrating duration of sample collection for various enable levels.

the 0.61 m H-flumes on the agricultural watersheds, increased enable levels ranged from 38 to 305 mm (0.001 to 0.06 m³/s). Increased enable levels ranged from 137 to 762 mm (0.02 to 0.49 m³/s) for the airport site and from 519 to 1067 mm (0.04 to 1.06 m³/s) for the mixed urban site. An example storm is presented in Figure 1 to illustrate the duration of sample collection for various hypothetical enable levels.

RESULTS AND DISCUSSION

Runoff events.—Dissolved NO₃+NO₂-N loads for each site were analyzed for a total of 122 measured runoff events over two years. A summary of rainfall and runoff data for events in which samples and flow rate data were collected from both sites in the urban and agricultural watersheds is presented in Table 2. A wide range of rainfall depths and intensities, runoff volumes, and peak flow rates occurred during the study period.

Results from this study match well with information provided by Slade (pers. comm.) and other studies such as Tate et al. (1999) that generally report that three to six events per year create about 75% of the annual storm runoff and NPS load. Our results for these study sites
Table 2. Properties of rainfall and runoff events.

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Precision</th>
<th>Airport</th>
<th>Mixed Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of runoff events</td>
<td>24</td>
<td>18</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Peak flows (m$^3$/s)</td>
<td>0.00 - 0.32</td>
<td>0.00 - 0.39</td>
<td>0.02 - 4.91</td>
<td>0.03 - 9.82</td>
</tr>
<tr>
<td>Runoff volumes (m$^3$)</td>
<td>0.14 - 946</td>
<td>0.15 - 2260</td>
<td>39 - 77000</td>
<td>109 - 89000</td>
</tr>
<tr>
<td>Runoff depths (mm)</td>
<td>0.00 - 36</td>
<td>0.00 - 25</td>
<td>0.10 - 205</td>
<td>0.20 - 134</td>
</tr>
<tr>
<td>Rainfall (mm)</td>
<td>8 - 63</td>
<td>9 - 63</td>
<td>5 - 227</td>
<td>4 - 187</td>
</tr>
<tr>
<td>Max 15 min rainfall (mm)</td>
<td>19</td>
<td>19</td>
<td>26</td>
<td>26</td>
</tr>
</tbody>
</table>

showed that three to six events per year produced on average from 74 to 87% of the NO$_3$+NO$_2$-N load and that between 64 and 100% of the annual load could have been captured by sampling only the largest six storms each year (Table 3).

As enable levels increase, an increasing amount of pollutant flux is not captured; therefore, increasing enable levels results in increased error compared to the true or total load. To quantify these increases, relative errors (percent deviation from the total measured load) and absolute errors (magnitude of deviation from the total measured load) were calculated. Figures 2 and 3 illustrate that errors increase rapidly as enable levels increase, especially for the smaller watersheds. Errors for the smaller agricultural watersheds were substantial even for small increases in enable levels because small increases in enable level resulted in relatively large increases in flow rates and because large changes in nutrient concentration occurred during the storms events; therefore, substantial flow volume and nutrient flux were not sampled with increased minimum flow thresholds.

In most water quality sampling projects, appropriate sampling to adequately measure loads must be conducted within the constraint of limited project resources. To reduce analysis costs and overcome laboratory time and personnel limitations, the number of samples can be managed by raising enable levels, increasing duration or flow volume between samples and/or compositing several samples together. However, when each of these adjustments are made errors in pollutant flux measurements increase. Based on the results of this study and comparisons to King & Harmel (2001), enable levels should be raised only after
Table 3. Annual NO₃+NO₂-N loads determined by measuring the largest storm events.

<table>
<thead>
<tr>
<th>Measure only the Largest (Number of events)</th>
<th>Percent of Measured Annual Load (Average)</th>
<th>(Standard deviation)</th>
<th>(Range)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>49</td>
<td>±25</td>
<td>16 - 89</td>
</tr>
<tr>
<td>2</td>
<td>64</td>
<td>±26</td>
<td>27 - 97</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>±23</td>
<td>38 - 98</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>±20</td>
<td>49 - 100</td>
</tr>
<tr>
<td>5</td>
<td>84</td>
<td>±17</td>
<td>58 - 100</td>
</tr>
<tr>
<td>6</td>
<td>98</td>
<td>±15</td>
<td>64 - 100</td>
</tr>
</tbody>
</table>

careful consideration of the resulting consequences, since small increases in enable levels resulted in large errors. King & Harmel (2001) showed that increasing the duration between samples from 5 min to 15 min, which reduced the number of samples by 66%, resulted in less than 1% average increases in relative error. Even when samples were composited up to six samples per bottle, which further reduced samples numbers by 83%, less than 20% average increases in relative error occurred. In contrast to relatively small increases in relative error for increased duration and flow volume presented by King & Harmel (2001), relative errors increased rapidly when minimum flow thresholds were raised for the watersheds in this study. Figure 4 illustrates that less error is introduced with corresponding reduction in sample numbers by increasing duration or flow volume between samples, with further reduction possible with composite sampling. This figure presents the most valuable result of these analyses: alternative strategies are recommended over raising minimum flow thresholds. Minimum flow thresholds should be set at low levels, such that even small storms with small increases in flow depth are sampled. On watersheds of the size studied (6 to 67 ha), minimum flow thresholds of 0.001 to 0.04 m³/s are recommended.

**Conclusions**

As human population grows and water resources increase in value from a water supply and an aquatic ecosystem standpoint, accurate characterization of water quality will become more important. In order to correctly quantify total water quality constituent fluxes, the traditional methodology of periodic low flow grab sampling to characterize point sources must be coupled with storm flow monitoring to characterize
Figure 2. Relative and absolute errors the small agricultural watersheds for various minimum flow thresholds.

Figure 3. Relative and absolute errors the larger urban watersheds for various minimum flow thresholds.
Comparison of measured nutrient fluxes to hypothetical fluxes collected under various enable level scenarios in this study showed that substantial error is introduced as minimum flow thresholds are increased. Based on this comparison, minimum flow thresholds for automated sampling equipment should be programmed such that even small storms with small increases in flow depth are sampled. On smaller watersheds, minimum flow thresholds of 0.001 to 0.04 m³/s are recommended. In order to manage the number of samples collected, enable levels should not be raised above these levels without careful consideration of consequences. Alternatives for managing sample

Figure 4. Comparison of relative errors for various sampling strategies to manage the number of samples.
numbers, such as increasing the time or flow volume between samples, or compositing several samples, introduce substantially less error in nutrient flux measurements for the watersheds studied.

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We would like to thank Kirk Dean, PhD, Principal Scientist, Parsons Engineering Science; Christine Kolbe, Aquatic Scientist, Texas Natural Resource Conservation Commission (TNRCC); and Roger Miranda, Geochemist, TNRCC for review of an earlier version of this manuscript. Raymond M. Slade, Jr., hydrologist and Texas District Surface-Water Specialist for the U.S Geological Survey, also deserves credit for providing valuable insight and information on the subject of storm water sampling. Trade names in this manuscript are included for the benefit of the reader and do not imply endorsement by USDA.

LITERATURE CITED


D.C., 572 pp.

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The northern pygmy mouse, *Baiomys taylori*, is a southern species that reaches its northern distributional limits in Texas, New Mexico and Oklahoma (Choate et al. 1990; Stuart & Scott 1992; Tumlison et al. 1993). They usually are found in association with cotton rats (*Sigmodon*) and harvest mice (*Reithrodontomys*), and prefer grassy areas such as old fields, pastures and along railroads or highways (Schmidly 1983). Their distribution in Texas currently is thought to range from along the coast and throughout the central portions of the state to western Texas, excluding the Trans-Pecos and northeastern Texas (Davis & Schmidly 1994). Fieldwork in Nacogdoches County has documented the northern pygmy mouse at one site beyond the distribution reported by Davis & Schmidly (1994).

On 9 and 10 October 1999, eight *Baiomys taylori* were collected from Nacogdoches County, Alazon Bayou Wildlife Management Area, near the Angelina River (31° 29.7' N, 94° 45.2' W). Specimens were collected in Sherman live traps set in an old field bordered by a pine forest. The specimens were deposited in the Angelo State Natural History Collections (ASNHC 11054-11061) as museum study skins and skeletons. Average measurements (range shown in parentheses), in mm, for the specimens (*n*=8) were: total length, 102 (91-110); length of tail, 41 (39-44); length of hind foot, 13 (13-14); length of ear, 10 (10-12). The specimens had an average mass of 7.7 grams (6g-11g). One female had two embryos, one in each uterine branch, measuring 10 mm (crown-rump length). Other rodents collected at this locality were *Sigmodon hispidus*, *Reithrodontomys fulvescens*, *Geomys breviceps* and *Ochrotomys nuttalli*. 

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**GENERAL NOTES**

**REEXAMINATION OF THE RANGE FOR THE NORTHERN PYGMY MOUSE, *Baiomys taylori* (RODENTIA: MURIDAE), IN NORTHEASTERN TEXAS**

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The northern pygmy mouse, *Baiomys taylori*, is a southern species that reaches its northern distributional limits in Texas, New Mexico and Oklahoma (Choate et al. 1990; Stuart & Scott 1992; Tumlison et al. 1993). They usually are found in association with cotton rats (*Sigmodon*) and harvest mice (*Reithrodontomys*), and prefer grassy areas such as old fields, pastures and along railroads or highways (Schmidly 1983). Their distribution in Texas currently is thought to range from along the coast and throughout the central portions of the state to western Texas, excluding the Trans-Pecos and northeastern Texas (Davis & Schmidly 1994). Fieldwork in Nacogdoches County has documented the northern pygmy mouse at one site beyond the distribution reported by Davis & Schmidly (1994).

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These records are approximately 50 miles (80 km) northeast of the reported range for *B. taylori* by Davis & Schmidly (1994) and 85 miles (136 km) south of the Harrison County record reported by Baccus et al. (1971). The range of this species has been continually expanding northward (Choate et al. 1990) since it was described from Duval County in southern Texas (Thomas 1887). Bailey (1905) indicated that *B. taylori* was restricted to southern and coastal Texas. Since then it has been moving northwest into central Texas and the Llano Estacado (Davis 1974; Stangl et al. 1983; Jones & Manning 1989; Pitts & Smolen 1989; Choate et al. 1990). Recently it has extended its range to include New Mexico and Oklahoma (Stangl & Dalquest 1986; Stuart & Scott 1992; Tumlison et al. 1993).

The extent of the northeastern range of this species has been unclear in the last 30 years. Baccus et al. (1971) reported a specimen from Harrison County, Texas. This specimen extended the range of *B. taylori* to the northeast by over 100 miles (>160 km). Davis (1974) reported the range of *B. taylori* in Texas as extending from Cooke County to Jefferson County excluding northeastern Texas and the Harrison County record (Fig. 1). In Davis & Schmidly (1994), the reported range was similar to that given in Davis (1974), with the Harrison County record listed as outside the range of the species. Hall (1981), Schmidly (1983) and Cameron (1999) depicted the range of *B. taylori* as including most of northeastern Texas, extending from Cooke County east to Harrison County and continuing south parallel to the Louisiana border to Orange County, Texas (Fig. 1). Recent records from Anderson County (Roberts et al. 1997) and the records reported in this study appear to support the range reported by Hall (1981), Schmidly (1983) and Cameron (1999). Further research into the northeastern extent of the range of *Baiomys taylori* is needed.

**ACKNOWLEDGMENTS**

Thanks are due to the Texas Parks and Wildlife Department for allowing research and collection at Alazon Bayou Wildlife Management Area. We thank Michael Poteet and other wildlife biologists at Alazon Bayou Wildlife Management Area, for assistance while at the site. Mark Boyle, Stephanie Franklin, Eddie Lyons, Marisol Salazar, Bill Scoggins and Clay White assisted in field collecting. Richard Humbertson and Brandy Martin were instrumental in preparing and cataloging specimens into the Angelo State Natural History Collections.
Figure 1. Map showing the northeastern distributional limit of *Baiomys taylori* in Texas. Solid line indicates the range limit proposed by Davis (1974) and Davis & Schmidly (1994). Dashed line indicates the range limit proposed by Hall (1981), Schmidly (1983) and Cameron (1999). Solid circles indicate county records for *Baiomys taylori* and solid triangle represents county records reported in this study.

Darin Carroll and Clyde Jones provided comments on an earlier draft of this manuscript.

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RESPONSE OF HERBACEOUS VEGETATION TO SUMMER FIRE IN THE WESTERN SOUTH TEXAS PLAINS

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Chaparral Wildlife Management Area, P.O. Box 115
Artesia Wells, Texas 78001

Abstract.—With increases in wildlife related enterprises and ecological restoration efforts in southern Texas, there is an increased interest in utilizing summer fire to achieve management goals; yet, there is little data on the effects of summer burning on vegetation and wildlife. Herbaceous vegetation diversity, productivity, density and frequency were estimated on five summer burned and five nontreated sites utilizing 20 by 50 cm quadrats. Forb density and frequency was monitored for two growing-seasons postburn. Grass indices were measured three months postburn. Grass and forb yields were estimated in 0.25 m² plots during the first growing-season postburn. *Croton* (*Croton* sp.) responded positively to summer burning during the first growing-season postburn for all indices measured. During the second growing season postburn, *Croton* densities were similar among treatments. Densities of erect dayflower (*Commelina erecta*) and beach groundcherry (*Physalis cinerascens*) were greatest on burned sites throughout the study. Silky evolvulus (*Evolvulus alsinoides*) and hoary blackfoot (*Melampodium cinereum*) were more common on nontreated sites. Grass densities were lowest on burned sites three months postburn, and yields were similar between treatments by the middle of the first postburn growing season. Summer burning does not appear to provide any additional benefits in forb response over dormant-season burning. The long-term effect of a regimented burning regime on vegetation and influence of burn season on wildlife is not clearly understood and warrants further investigation.

The Rio Grande Plains of south Texas is the southern-most extension of the Great Plains Grasslands. Fire, along with other climatic variables such as drought, presumably maintained the honey mesquite (*Prosopis glandulosa*) savannas and interspersed grasslands of pre-European settlement south Texas (Scifres & Hamilton 1993). Frequency of fire appeared to be highly variable and ranged from 5-30 years (Wright & Bailey 1982). Following European settlement, suppression of fire combined with heavy livestock grazing has lead to the current thorn woodlands common throughout southern Texas (Archer et al. 1988; Archer 1994).

Beginning in the mid-twentieth century, south Texas landowners began to convert these thorn woodlands back to grasslands to enhance rangelands for livestock production. Mechanical treatments such as root plowing were commonly utilized methods for achieving this goal. Mechanical brush manipulation practices can significantly reduce woody plant cover while increasing herbaceous vegetation (Scifres et al. 1976;
Bozzo et al. 1992). However, once treated rangelands are revegetated by woody species, woody plant diversity can be dramatically reduced (Fulbright & Beasom 1987; Ruthven et al. 1993), which may negatively impact diversity of wildlife species.

Land ownership and land use practices in south Texas have changed in recent years. The size of individual landholdings has decreased and revenues derived from those properties have become increasingly dependent on wildlife rather than traditional livestock operations. Many wildlife management programs are directed towards game species such as white-tailed deer (*Odocoileus virginianus*) and northern bob white (*Colinus virginianus*). In the southeastern United States, prescribed fire has long been utilized to manage habitat for northern bobwhite (Landers & Mueller 1992). Woody vegetation is a primary component of white-tailed deer diet in south Texas (Drawe 1968; Taylor et al. 1997), and prescribed burning in eastern portions of the Rio Grande Plains can reduce brush cover while maintaining woody plant diversity (Box & White 1969). Dormant-season prescribed burning in southern Texas has been shown to increase herbaceous vegetation preferred by wildlife (Hansmire et al. 1988; Ruthven et al. 2000). As a result of its reported benefits, south Texas rangeland managers are beginning to utilize prescribed fire to enhance wildlife habitat.

In addition to the rise of wildlife related enterprises, there is growing interest in restoring ecosystems to pre-European settlement conditions. Many proponents of ecological restoration promote the use of summer burning to mimic the occurrence of natural fires. Most perennial grasses generally decrease following summer burns (Scifres & Duncan 1982; Engle et al. 1993; Engle et al. 1998). In Oklahoma, summer fire can increase forb productivity (Engle et al. 1998), while in southern Texas summer prescribed burns appeared to have little affect on forbs (Mayeux & Hamilton 1988). Although effects of summer fire are documented in many ecosystems, little information is available on the response of vegetation and wildlife to growing-season fire in the more xeric areas of the western Rio Grande Plains.

The objective of this study was to determine the effects of summer prescribed fire on the diversity, density and productivity of herbaceous vegetation during the first and second growing-seasons post-treatment in the western Rio Grande Plains. It is hypothesized that prescribed burning south Texas rangelands during the growing season will result in enhanced germination and establishment of annual and perennial forbs and decreases of perennial grasses.
Figure 1. Location of the Chaparral Wildlife Management Area within the South Texas Plains ecological region (stippled area) and the state of Texas. South Texas Plains ecological region boundaries were taken from Hatch et al. (1990).

MATERIALS AND METHODS

The study area (Fig. 1) was located on the Chaparral Wildlife Management Area (28° 20' N, 99° 25' W) within the western South Texas Plains (Correll & Johnston 1979; Hatch et al. 1990) and northern portion of the Tamaulipan Biotic Province (Blair 1950). Climate is characterized by hot summers and mild winters with an average daily minimum winter (January) temperature of 5°C, an average daily maximum summer (July) temperature of 37°C, a growing season of 249 to 365 days, and average annual precipitation (1951-1978) of 55 cm (Stevens & Arriaga 1985). Average annual precipitation on the study site (1989-1999) was 54 cm. Precipitation patterns are bimodal with peaks occurring in late spring (May to June) and early fall (September to October).

Five sites subjected to prescribed burns were paired with five nontreated sites utilizing a randomized block design. Study sites were approximately 2 ha in size. Burned sites were located within larger
areas that had been burned. Rangeland fire in southern Texas typically produces a mosaic of burned and nonburned areas as a result of uneven fuel loads (Box & White 1969). All study sites received 100% coverage by burns. Fire was applied to burn sites in August 1999. Relative humidity and air temperature, using a sling psychrometer, and surface wind speed, using the Bufort Scale, were estimated before ignition and at the completion of each fire. Weather conditions were relatively constant during all fires with a relative humidity of 32%, temperature of 39°C and wind speed of 8 kph. Wind direction was variable. Soil moisture was not recorded. All burns were conducted 3 to 5 days following a 23 cm rainfall event (Hurricane Brett) and soil moisture was considered high. Because of variable wind speed and direction during burns and uneven fuel loads, rate of spread and flame height were highly variable and not recorded. Fuel loads appeared to vary within study sites. Adequate fuel loads for burning in western portions of south Texas are ≥ 2,000 kg/ha and study sites met these levels based on visual estimations. All burns were ignited as head fires with drip torches.

Soils were similar among sites and consisted of Duval fine sandy loam, gently undulating, Duval loamy fine sand, 0 to 5% slopes, and Dilley fine sandy loam, gently undulating (Stevens & Arriaga 1985; Gabriel et al. 1994). Duval series soils are fine-loamy, mixed, hyperthermic Aridic Haplustalfs and belong to the Sandy Loam range site. Dilley series soils are loamy, mixed, hyperthermic shallow Ustalfic Haplargids and belong to the Shallow Sandy Loam range site. Topography was nearly level to gently sloping and elevation ranged between 177 and 186 m.

Vegetation is characterized by a two-phase pattern of shrub clusters scattered throughout a grassland/savanna (Whittaker et al. 1979; Archer et al. 1988). Plant communities were characteristic of the *P. glandulosa* -granjeno (*Celtis pallida*) association (McLendon 1991). Subdominant woody species include twisted acacia (*Acacia schaffneri*), brazil (*Condalia hookeri*) and hog-plum (*Colubrina texana*). Woody plant canopy cover was similar among all sites and averaged 40% (Gabor 1997). Prominent herbaceous species included Lehmann lovegrass (*Eragrostis lehmanniana*), fringed signalgrass (*Brachiaria ciliatissima*), hairy grama (*Bouteloua hirsuta*), croton (*Croton sp.*), coreopsis (*Coreopsis nuccensoides*), lazydaisy (*Aphanostephus sp.*) and partridge pea (*Chamaecrista fasciculata*) (Ruthven et al. 2000; 2002). Pretreatment sampling of herbaceous vegetation was not conducted; however, dominant herbaceous species are generally uniform in distribu-
tion across shrub clusters and the interspace (Whittaker et al. 1979; Ruthven 2001) and the assumption was made that all study sites were similar prior to application of burning treatments.

Domestic livestock have grazed the study area since the 18th century (Lehmann 1969). Cattle were the major species of livestock since about 1870, prior to which sheep production dominated from about 1750 to 1870. Before 1969, grazing by cattle was continuous. From 1969 to 1984, livestock managers utilized a four-pasture rest rotation system of cattle grazing. Cattle were absent from the study site during 1984 to 1989. Since 1990, including the timeframe of this study, the study area has been grazed using stocker cattle under a high intensity, low frequency grazing system during the period October through April. Stocking rates were considered low to moderate and averaged one Animal Unit per 12 ha. Postburn grazing on the study site has little affect on forb response (Ruthven et al. 2000).

Forb and grass density and frequency were estimated by counting individual plants in 50, 20 by 50 cm quadrats placed randomly in each study site. Forbs were sampled in fall (November) 1999 and spring (March-April) 2000 and 2001. Grass density and frequency were estimated in fall 1999. Frequency of occurrence data was used to estimate species richness, diversity and evenness. Forb and grass species diversity (H') and evenness (J') was quantified with Shannon's Index (Chambers & Brown 1983). In June 2000, grass and forb yields were estimated in 10, 0.25 m² plots randomly placed in each study site. Aboveground biomass was clipped in each plot. Current years’ growth was separated by species, air dried at 40°C, and weighed to the nearest 0.1 g. Scientific nomenclature and vernacular names of plants follow Hatch et al. (1990).

Forb frequency and density estimates were analyzed with a two-way analysis of variance (ANOVA), with treatment and season as the main effects and a treatment by season interaction. Tukey’s HSD was used to make comparisons of seasonal means. Grass density and frequency and yield data were analyzed by a one-way ANOVA. All statistical comparisons were considered significant at $P \leq 0.05$.

RESULTS

Forb richness and diversity was similar among treatments (Table 1). Richness and diversity varied by season with greatest values in spring 2001 than spring 2000 and fall 1999 and spring 2000 exhibiting greater values than fall 1999. An interaction existed for richness and evenness,
Table 1. Forb species richness, diversity and evenness by season on summer burned \((n = 5)\) and nontreated \((n = 5)\) sites on the Chaparral Wildlife Management Area, Dimmit and La Salle Counties, Texas, 1999-2001.

<table>
<thead>
<tr>
<th>Season/treatment</th>
<th>Richness (\bar{x}) (SD)</th>
<th>Diversity (\bar{x}) (SD)</th>
<th>Evenness (\bar{x}) (SD)</th>
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<tbody>
<tr>
<td>Fall 1999</td>
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<tr>
<td>Burned</td>
<td>10.2 ± 3.4</td>
<td>2.05 ± 0.31</td>
<td>0.91 ± 0.04</td>
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<tr>
<td>Nontreated</td>
<td>17.2 ± 4.5</td>
<td>2.23 ± 0.34</td>
<td>0.79 ± 0.07</td>
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<td>Spring 2000</td>
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<tr>
<td>Burned</td>
<td>21.0 ± 3.6</td>
<td>2.44 ± 0.2</td>
<td>0.80 ± 0.04</td>
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<tr>
<td>Nontreated</td>
<td>22.6 ± 5.1</td>
<td>2.67 ± 0.31</td>
<td>0.86 ± 0.02</td>
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<td>Spring 2001</td>
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<tr>
<td>Burned</td>
<td>33.2 ± 3.6</td>
<td>2.85 ± 0.18</td>
<td>0.81 ± 0.02</td>
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<tr>
<td>Nontreated</td>
<td>31.0 ± 2.2</td>
<td>2.91 ± 0.04</td>
<td>0.83 ± 0.02</td>
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<td>0.1408</td>
<td>0.1024</td>
<td>0.3780</td>
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<td>Season</td>
<td>&lt;0.0001</td>
<td>&lt;0.0001</td>
<td>0.2660</td>
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<td>Interaction</td>
<td>0.0419</td>
<td>0.7443</td>
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with greater species on nontreated sites in fall 1999 and greater evenness on burned sites in fall 1999 and nontreated sites in spring 2000. Grass richness \((P = 0.1930)\), diversity \((P = 0.6968)\) and evenness \((P = 0.3972)\) was similar between burned \([12.0 ± 0.9 (\bar{x} ± SD), 2.11 ± 0.16 and 0.85 ± 0.04, respectively]\) and nontreated \([13.4 ± 0.9, 2.15 ± 0.16, and 0.83 ± 0.02]\) sites.

Total forb density was similar \((P = 0.6914)\) among burned \((fall 1999, 11.5 ± 6.9 \text{ plants/m}^2; spring 2000, 78.7 ± 22.8; spring 2001, 222.7 ± 86.8)\) and nontreated \((fall 1999, 19.9 ± 8; spring 2000, 32 ± 8.9; spring 2001, 243.6 ± 33.8)\) sites and varied \((P < 0.0001)\) by season. Forb densities in fall 1999 were similar to spring 2000 with spring 2001 being greater than both fall 1999 and spring 2000. Densities of many dominant \((\text{frequency} > 5\%)\) forbs utilized by livestock and wildlife \((\text{Everitt et al.} 1999)\) varied by treatment and season (Table 2). Croton, erect dayflower \((\text{Commelina erecta})\) and beach groundcherry \((\text{Physalis cinerascens})\) densities were greatest on burned sites, whereas silky evolvulus \((\text{Evolvulus alsinoides})\) and hoary blackfoot \((\text{Melampodium cinereum})\) were greatest on nontreated sites. Aphanostephus sp., C. nucenoides, rose ring Indian blanket \((\text{Gallardia pulchella})\), Dillens oxalis \((\text{Oxalis dillenii})\) and Hooker plantain \((\text{Plantago hookeriana})\) varied seasonally in the order: fall 1999 = spring 2000 < spring 2001.

Croton varied by season in the order: spring 2000 > spring 2001 = fall 1999. Density of \(C. \text{fasciculata}\) was similar between fall 1999 and spring 2000, spring 2001 was similar to spring 2000, and spring 2001 was greater than fall 1999. Density of \(E. \text{alsinoides}\) varied by season in the order: fall 1999 = spring 2000 > spring 2001. Density of
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Table 3. Density (plants/m²) and percent frequency (%) of dominant (frequency > 5%) grasses and sedges on summer burned (n = 5) and nontreated (n = 5) sites on the Chaparral Wildlife Management Area, Dimmit and La Salle counties, Texas, November 1999.

<table>
<thead>
<tr>
<th>Class/species</th>
<th>Density</th>
<th>Frequency</th>
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<td>Burned</td>
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<tr>
<td>Aristida purpurea</td>
<td>0.6</td>
<td>0.4</td>
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<tr>
<td>Cyperus retroflexus</td>
<td>0.1</td>
<td>0.2</td>
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<tr>
<td>Brachiaria ciliatissima</td>
<td>1.8</td>
<td>1.6</td>
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<tr>
<td>Bouteloua hirsuta</td>
<td>9.0</td>
<td>8.0</td>
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<tr>
<td>Chloris coccullata</td>
<td>0.4</td>
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<tr>
<td>Digitaria cognata</td>
<td>4.2</td>
<td>1.1</td>
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<tr>
<td>Eragrostis lehmanniana</td>
<td>2.3</td>
<td>1.1</td>
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<tr>
<td>Eragrostis sessilisepica</td>
<td>0.5</td>
<td>0.4</td>
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<tr>
<td>Eragrostis secundiflora</td>
<td>0.8</td>
<td>0.7</td>
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<tr>
<td>Paspalum setaceum</td>
<td>5.4</td>
<td>3.6</td>
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<tr>
<td>Setaria firmulum</td>
<td>1.0</td>
<td>1.3</td>
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silvery bladderpod (Lesquerella argyaea) was greatest in spring 2001 followed by spring 2000, which was greater than fall 1999. Croton and E. alsinoides exhibited an interaction, with Croton having greatest densities on burned sites in spring 2000 and E. alsinoides densities being greatest on nontreated sites in fall 1999. Grass density was greater (P = 0.0044) on nontreated (51.5 ± 7.4) than burned (28 ± 11.2) sites. Oneflower flatsedge (Cyperus retroflexus), B. ciliatissima and E. lehmanniana densities were highest on nontreated sites (Table 3).

Croton, C. erecta and P. cinerascens were most common on burned sites, while E. alsinoides and M. cinereum were more frequently encountered on nontreated sites (Table 4). Seasonal variations followed similar tends as density estimates. Treatment by season interactions for Croton and E. alsinoides were similar to density trends. Brachiaria ciliatissima and B. hirsuta were more commonly encountered on nontreated sites (Table 3).

Grass (P = 0.4701) and forb (P = 0.1356) productivity was similar between burned (133.9 ± 46.3 g/m²; 27.6 ± 28.2, respectively) and nontreated (122.8 ± 41.6; 6.4 ± 4.7, respectively) sites. Yield of grass
Table 4. Percent frequency (%) of dominant (frequency >5%) forbs utilized by livestock and wildlife (Everitt et al. 1999) by season on summer burned (n = 5) and nontreated (n = 5) sites on the Chaparral Wildlife Management Area, Dimmit and La Salle counties, Texas.

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<thead>
<tr>
<th>Species</th>
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<th>Fall 1999</th>
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<td>Helianthus x x x x x x x x linearifolius</td>
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<td>0.0%</td>
</tr>
<tr>
<td>Helianthus x x x x x x x x petiolaris</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Helianthus x x x x x x x x roseus</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Helianthus x x x x x x x x x hybridus</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Helianthus x x x x x x x x x hirsutus</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Table 5. Yield (g/m²) of selected grasses and forbs season on summer burned (n = 5) and nontreated (n = 5) sites on the Chaparral Wildlife Management Area, Dimmit and La Salle counties, Texas, June 2000.

<table>
<thead>
<tr>
<th>Class/Species</th>
<th>Burned</th>
<th>Nontreated</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \bar{x} )</td>
<td>SD</td>
<td>( \bar{x} )</td>
</tr>
<tr>
<td>Grass</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aristida purpurea</td>
<td>14.3</td>
<td>12.5</td>
<td>13.4</td>
</tr>
<tr>
<td>Brachiaria ciliatissima</td>
<td>0.5</td>
<td>0.7</td>
<td>8.4</td>
</tr>
<tr>
<td>Bouteloua hirsuta</td>
<td>22.5</td>
<td>17.7</td>
<td>30</td>
</tr>
<tr>
<td>Chloris cucullata</td>
<td>2.2</td>
<td>3.4</td>
<td>0.6</td>
</tr>
<tr>
<td>Digitaria cognata</td>
<td>12.0</td>
<td>6.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Eragrostis lehmanniana</td>
<td>41.0</td>
<td>17.7</td>
<td>30.7</td>
</tr>
<tr>
<td>Eragrostis sessilispsica</td>
<td>5.6</td>
<td>5.8</td>
<td>4.7</td>
</tr>
<tr>
<td>Eragrostis secundiflora</td>
<td>3.8</td>
<td>3.6</td>
<td>5.9</td>
</tr>
<tr>
<td>Paspalum setaceum</td>
<td>11.7</td>
<td>5.1</td>
<td>7.0</td>
</tr>
<tr>
<td>Forbs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chamaecrista fasciculata</td>
<td>3.9</td>
<td>4.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Croton sp.</td>
<td>7.5</td>
<td>5.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Commelina erecta</td>
<td>1.6</td>
<td>2.5</td>
<td>0</td>
</tr>
<tr>
<td>Evolvulus sp.</td>
<td>1.9</td>
<td>2.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>

species was similar among treatments (Table 5). Croton yield was greatest on burned sites.

**DISCUSSION**

The results of this study indicate that summer applied prescribed fire on south Texas rangelands can increase densities and productivity of important seed producing annuals such as Croton during the first growing season following burning. Croton, which is an important seed source for granivorous birds (Dillon 1961; Everitt et al. 1999), also responds positively to winter burning throughout the South Texas Plains (Box & White 1969; Hansmire et al. 1988; Ruthven et al. 2000). Annual sunflowers (Helianthus sp.) are another important seed producer that also provide forage for O. virginianus and livestock (Everitt et al. 1999). Although not significantly affected by burning, prairie sunflower (Helianthus petiolaris) was only encountered on burned sites. Chamaecrista fasciculata was one of the most common annual forbs encountered and the lack of treatment effect was similar to that resulting from winter burning (Ruthven et al. 2000; 2002). Chamaecrista fasciculata, which is important forage for C. virginianus, typically increases following winter and spring burns in the southeastern United States (Lewis & Harshbarger 1976). Cushwa et al. (1968) reported that moist heat greatly increases the germination of partridge pea. Although soil moisture conditions were considered high during the burns in this study, the lack of a response by C. fasciculata may have resulted from high temperatures associated with the fire and season of burn. Controlled
laboratory experiments simulating heat produced by prescribed fire have shown no increase in germination of *C. fasciculata* seed following exposure to heat of < 600°F (Mitchell & Dabbert 2000). Additionally, much of *C. fasciculata* seed may be exposed on the soil surface during summer and consequently consumed by fires.

Cool season annual forbs appeared unaffected by summer burning, which may be explained by abnormal precipitation patterns. In southern Texas, cool season annuals germinate in fall and reach peak flowering in early spring. Precipitation (7.5 cm) during this time period (October 1999 to February 2000) was 56% below normal, which may have negated any positive responses from burning. The varied response by perennials was similar to dormant-season fire (Hansmire et al. 1988; Ruthven et al. 2000). *Commelina erecta* and *P. cinerascens* slightly increased following winter burns in the western South Texas Plains (Ruthven et al. 2000), while in the transition zone between the South Texas Plains and the Gulf Coast Prairies both species were unaffected or slightly decreased following winter burning (Hansmire et al. 1988). *Commelina erecta* and *P. cinerascens* are important forages for a wide variety of wildlife. *Commelina erecta* is highly valued as forage for *O. virginianus* (cf. Everitt et al. 1999) and an important dietary component of the Texas tortoise (*Gopherus berlandieri*) (R. Kazmaier, pers. comm.), and the leaves and fruits of *P. cinerascens* are important foods of *O. virginianus*, javelina (*Tayassu tajacu*) and wild turkey (*Meleagris gallopavo*) (cf. Everitt et al. 1999). Competition among herbaceous vegetation may explain the varied response of perennial forbs to burning. Declining perennials such as *M. cinereum* and *E. alsinoides* are found primarily in the interspace between shrub clumps where grass and annual forb abundance is greatest, whereas perennials such as *C. erecta* and *P. cinerascens*, which demonstrated postburn increases, are primarily found beneath *P. glandulosa* canopies in shrub clusters where grass and forb abundance are less than the interspace (Whittaker et al. 1979; Ruthven 2001). Increases in annual forbs in the interspace following burning may increase competition resulting in declines of *M. cinereum* and other perennials on burned sites.

Although burning increased *Croton* during the first growing season postburn, this positive affect did not persist into the second growing season. This response was similar to winter burns conducted on the study site (Ruthven et al. 2002). It is unclear whether increases in forb densities in the first growing season result in an increase in availability of seeds for use by wildlife and future forb production. It does appear that additional disturbance is necessary to stimulate a significant increase
in germination of annual forbs. The extension of the positive response of some perennials into the second growing season on burned sites is similar to that observed on comparable study sites burned during winter. Increases in perennials may be explained by the release of nutrients into the soil (Scifres & Hamilton 1993).

In part, seasonal variation of warm-season annuals can be explained by season of burn. Warm-season annual forbs would have been consumed by summer fires, explaining their absence during the fall 1999 sampling period. Seasonal variability and interactions are also a likely result of precipitation patterns. Atypical drought conditions persisted throughout late summer and early fall 2000, with 1.7 cm of precipitation being recorded between mid-June and mid-October on the study site. This lack of rainfall may have lead to poor seed production of warm-season annuals such as Croton and rough buttonweed (Diodia teres), resulting in low numbers in spring 2001. The perennial forb E. alsinoides may have suffered mortality during this extended dry period, resulting in the decreased densities observed in spring 2001, while L. argyaea, which had greatest densities in spring 2001, appears more adapted to short-term periods of drought. In contrast to warm-season annual forbs, densities of cool-season annuals were greatest in spring 2001. Fall and winter (October-February) rainfall (30.9 cm) during 2000-2001 was 183% above normal compared to below normal precipitation recorded during the same period in 1999-2000.

The initial reduction of warm-season perennial grasses following summer burns was similar to that reported in other studies in the south central United States (Scifres & Duncan 1982; Mayeux & Hamilton 1988; Engle et al. 1998); however, productivity was similar among treatments midway through the first postburn growing season. Despite apparent grass mortality from fire, vigor of surviving plants appeared to be stimulated. This apparent increase in productivity may have resulted from soil moisture conditions at the time of burning. Soil moisture content in previous studies (Scifres & Duncan 1982; Mayeux & Hamilton 1988) was relatively low, while soil moisture was considered high in this study. Summer burns following significant precipitation events in northwestern Mexico were found to increase bufflegrass (Cenchrus ciliaris) productivity (Martin-R et al. 1999). Burning during the dormant and early growing season can also result in varied responses by grasses. Scifres & Duncan (1982) and Hansmire et al. (1988) reported overall increases in grass productivity following late winter and early spring burning, while Ruthven et al. (2002) reported that dormant-season burning had little affect on grass abundance.
Warm-season perennials such as tanglehead (*Heteropogon contortus*), plains bristlegrass (*Setaria machrostachya*) and multiflowered false rhodesgrass (*Chloris pluriflora*) dominated the Sandy Loam and Shallow Sandy Loam range sites of south Texas under pre-European settlement conditions (Stevens & Arriaga 1985). These grasses are highly preferred by livestock and have decreased as a result of long-term overgrazing. The occurrence of natural fires in the South Texas Plains may have been less frequent than other grassland/savanna ecosystems (Wright & Bailey 1982), and little data is available on how these historically dominant warm-season perennial grasses respond to fire season and frequency.

Invasion of sandy south Texas rangelands by *E. lehmanniana* is a growing concern. This introduced perennial is an aggressive invader that can displace native grasses and quickly become the predominant grass species (Anable et al. 1992). Although hot summer fires can kill *E. lehmanniana* (cf. Cable 1965), burning may increase germination of *E. lehmanniana* seed (Ryule et al. 1988). *Eragrostis lehmanniana* was reduced following fires in this study, but productivity on burned sites equaled nontreated site midway through the first postburn growing season. Extended monitoring beyond the first postburn growing season may be necessary to determine the full effects of growing-season burning on this species.

The grazing system employed on the study area appears to have little affect on the postburn response of forbs (Ruthven et al. 2000); however, it is unclear how grazing may have affected grasses following fire. High intensity low frequency grazing results in greater consumption of less-preferred forage species (Drawe 1988), which can lead to the more uniform grazing of herbaceous plants. The high intensity low frequency grazing system employed during the dormant-season on the study area appears to reduce selective grazing and minimize any effects postburn grazing pressure may have on grasses.

If enhancing annual forbs is a primary goal, then conducting summer burns on a biennial schedule may be beneficial. However, grass production must be taken into consideration, as grasses are the primary fine fuels needed to conduct prescribed burns in much of southern Texas. Proper grazing management is crucial in producing adequate fuel loads for burning. The grazing strategy on the study site, which provides rest during the majority (May-October) of the growing season, appears to allow for ample fuel buildups necessary to conduct burns successfully. Although repeated summer burns on a biennial schedule can increase herbaceous plant diversity and density and increase
dominance of grasses in mesic environments (Lewis & Harshbarger 1976), it is unclear whether similar responses can be achieved in dryer climes. Short-term periods of drought and highly variable rainfall are typical of the South Texas Plains (Norwine & Bingham 1985). This coupled with the semiarid (annual precipitation \( \leq 54 \text{ cm} \)) nature of western portions of the South Texas Plains may not provide adequate fuel loads on a regular basis to conduct burning on an alternating year schedule. Realistically, burning may be achieved on a three to four year cycle. This burning frequency may maintain benefits of burning on perennial forbs such as *C. erecta* and *P. cinerascens*. If prescribed burning activities are directed toward improving habitat for *O. virginianus*, it may be beneficial to limit the use of fire in areas dominated by highly preferred forage species such as *M. cinereum*, which respond negatively to fire.

Forb response to summer fire was similar to that of dormant-season burning. Most land managers burn during the winter months when burning conditions are less volatile. Based on forb response, there appears to be no benefit in conducting prescribed burns during the summer months rather than the dormant season. In fact, late winter fire can increase grass productivity. Although burning during winter or early spring may be preferred because winter fires are easier to control, there is little data on the effects of prescribed fire on wildlife. Most herpetofauna hibernate during the winter months. In south Texas, the Texas horned lizard (*Phrynosoma cornutum*), a state threatened species, hibernates at shallow depths (Fair & Henke 1997), which may increase its susceptibility to direct mortality during dormant-season fires. Burning during summer, when herpetofauna are active, may lessen the probability of direct mortality.

It is clear that climatic, edaphic and temporal factors can dramatically affect the impacts of prescribed burning. Response of forbs and grasses to fire can vary by burning date within a climatic season and among soil types (Hansmire et al. 1988) and care should be exercised when extrapolating the results of this study to other soil types in South Texas. Hiers et al. (2000) suggests that combinations of dormant- and growing-season burns may be necessary to promote species diversity. Further study into the effects of burning date within season, influence of pre- and postburn climatic variables, interactions between burning and herbivory, and long-term effects of multiple burns on vegetation, as well as wildlife, are necessary to better understand fire ecology in southern Texas.
ACKNOWLEDGMENTS

We thank Jim Gallagher with Texas Parks and Wildlife Department for assistance with statistical analyses. Rich Kazmaier with West Texas A&M University provided information on Texas tortoise (Gopherus berlandieri) diet.

LITERATURE CITED


Gabriel, W. J., D Arriaga & J. W. Stevens. 1994. Soil survey of LaSalle County, Texas,


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EFFECTS OF PRESCRIBED BURNING ON
VEGETATION AND FUEL LOADING IN
THREE EAST TEXAS STATE PARKS

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Abstract.—This study was conducted to evaluate the initial effectiveness of prescribed
burning in the ecological restoration of forests within selected parks in east Texas.
Twenty-four permanent plots were installed to monitor fuel loads, overstory, sapling,
seedling, shrub and herbaceous layers within burn and control units of Mission Tejas, Tyler
and Village Creek state parks. Measurements were taken during the summers of 1999 and
2000. Prescribed burning was conducted between these sampling periods in early spring
2000. Results indicated that the current applications of prescribed burning do not
significantly influence vegetation or fuels. Sustained drought, prior management practices
and imposed local burn bans reduced the window within which prescribed burns could be
applied, and limited the effectiveness of the burns.

Historically, fire has played an important role in most terrestrial
ecosystems. Fire has an influence in such ecosystem components as
recycling of nutrients, regulating plant succession and wildlife habitat,
maintaining biological diversity, reducing biomass, and controlling insect
and disease populations (Mutch 1994).

When conducted properly, prescribed fire undoubtedly alters the
composition and structure of the understory vegetation within forests. Several subclimax communities and endangered species of Texas are
dependent on fire. For example, fire is an essential element in the
restoration and management of longleaf pine (*Pinus palustris* Mill.)
stands and pitcher plant (*Sarracenia alata* Wood) wetland ecosystems. These and other communities benefit from an active prescribed burning
program (Reeves & Corbin 1985).

Prescribed burning is currently used as a management tool in several
Texas state parks for the purposes of reducing forest fuels, improving
wildlife habitat, altering the composition and structure of the understory
vegetation and enhancing park appearances. This study was conducted
to evaluate the initial effectiveness of prescribed burning in the
ecological restoration of forests and consisted of monitoring pre- and
post-burn vegetative characteristics and fuel loads at three Texas state parks. At Mission Tejas State Historical Park, Tyler State Park and Village Creek State Park, 24 plots, eight in each park, were monitored in the summers of 1999 and 2000 to determine short-term ecological effects of pre-scribed burning on vegetation and fuel loads.

**METHODOLOGY**

The three parks surveyed in this study were all part of the Pineywoods Region of Texas Parks and Wildlife Department’s Parks and Historic Sites. Mission Tejas and Tyler State Parks had similar ecological characteristics. Typical overstory species within the burn units of these parks included shortleaf pine (*Pinus echinata* Mill.), loblolly pine (*Pinus taeda* L.), sweetgum (*Liquidambar styraciflua* L.), water oak (*Quercus nigra* L.), white oak (*Q. alba* L.), mockernut hickory (*Carya tomentosa* (Poir.) Nutt.), white ash (*Fraxinus americana* L.) and American holly (*Ilex opaca* Ait.). Common understory species included yaupon (*Ilex vomitoria* Ait.), flowering dogwood (*Cornus florida* L.), American beautyberry (*Callicarpa americana* L.), longleaf uniola (*Chasmanthium laxum* var. *sessiliflorum* (L.) Yates), panicums (*Panicum* sp.) and various sedges (*Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b).

Average low temperatures in January range from 0 to 2°C, while July averages highs of 34 to 36°C. The first and last freezes typically occur around mid to late November and mid March to early April, respectively. Average rainfall exceeds 100 cm per year (*Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b*). Steep slopes abound in these parks, with elevation changes of 100 m within both parks (*Texas Parks and Wildlife 2000a; Texas Parks and Wildlife 2000b; Robinson & Blair 1997*). The historic fire return interval where these parks are located was 4 to 6 years. It is presently greater than 20 years (*Jurney 2000*) due to suppression, fragmentation and urbanization of the surrounding areas. Heavy fuel loads persist throughout the park due to decades of sporadic use of fire.

Unlike the others, Village Creek State Park included cypress swamps, bottomland wetlands and blackwater sloughs in the flood plain of the Neches River. The burn unit was once a longleaf/little bluestem (*Schizachyrium scoparium* (Michx.) Nash.) stand. Due to fire exclusion it was being overtaken by broadleaf trees, such as water tupelo (*Nyssa aquatica* L.), river birch (*Betula nigra* L.), water oak and redbay
(Persea borbonia (L.) Spreng.), in addition to the invasive Chinese tallowtree (Sapium sebiferum (L.) Roxb.). Common understory vegetative species included yaupon, flowering dogwood, American beautyberry, poison ivy (Toxicodendron radicans (L.) Kuntze), little bluestem, panicums and various sedges. The park’s mean elevation was 7 m. January’s average low temperature was 3°C, while July’s average high was 34°C (Texas Parks and Wildlife 2000c). Historic fire return interval in the area was 1 to 3 years. Now it is greater than 20 years (Jurney 2000).

Methods for establishing plots, and sampling vegetation and fuel loads were as defined in the National Park Service Western Region Fire Monitoring Handbook (Western Region Prescribed and Natural Fire Monitoring Task Force 1992). Plot size and sampling locations varied for each monitoring variable. Consistent sample areas were used between plots for each variable. The entire 20 by 50 m rectangular plot was used for sampling overstory (Figure 1). Overstory trees were defined as all trees, living or dead, with dbh > 15 cm. Dbh (diameter at breast height) was defined as diameter outside bark at 1.4 m.

Saplings were defined as standing living or dead trees with dbh ≥ 2.5 cm and ≤ 15 cm. They were sampled only within Quarter 1. Seedlings were defined as those living trees with dbh < 2.5 cm. Seedlings were monitored only in the 5 by 10 m medial section of Quarter 1.

The point line-intercept method was used for sampling shrub and herbaceous layers. The point line-intercept transect ran along the Q4-Q1 50 m line delineating that outside long axis of the plot. Height of the tallest living or dead individual by species, and species from tallest to shortest intercepting the transect were recorded.

To obtain shrub density, the Q4-Q1 transect was widened to a belt 0.5 m wide. A stem count of shrub species within the belt was recorded. To measure density of herbaceous plants, a 1 m² frame was placed on the plot side of both outer 50 m transects every 10 meters. The total area sampled in each plot using this method was 10 m². Herbaceous species and number of stems were recorded.

Four transects extending 15.2 m in random directions from the centerline at the 10, 20, 30 and 40 m marks in each plot were used to measure fuel loads (Brown et al. 1982). One-, ten-, hundred- and
thousand-hour fuels were sampled along these transects. Depth of Oᵢ and Oₑ (litter) horizons combined was also measured, as well as, depth of Oₐ (duff) horizon. Samples of Oᵢ and Oₑ horizons combined were collected and dried to determine litter weight. All vegetative and fuel load monitoring techniques were repeated during the same time of the year 2000.

Texas Parks and Wildlife Department (TPWD) personnel produced the burn plans. Prescribed burns were conducted during late February to early March 2000 when weather and fuel moisture conditions allowed.

To estimate the intensity of each burn, four tiles with heat-sensitive paint were attached to the center t-post of each plot. One tile each was placed 15 cm below ground, at ground level, 30 cm and 61 cm above ground. Tiles were removed immediately after the burn. Analyses of the tiles allowed an estimate within 38°C of the fire temperature at plot origin.
County burn bans prohibited burning in the parks until they were temporarily lifted following rain episodes. Because of the necessity to wait until a rain event, fuels were wet and resulting burns were weak and spotty. Firelines were monitored for two hours after each burn was completed. Park staff was responsible for monitoring the burn unit after that time.

According to written burn plans (Sparks 1999a; Sparks 1999b; Robinson & Blair 1997), the primary objectives of the initial burns were to reintroduce the natural role of fire into the ecosystems and to reduce fuel loads. Other objectives mentioned included reducing risk of wild-fire, increasing species richness and diversity, increasing wildlife habitat for numerous species, encouraging longleaf pine seedlings at Village Creek State Park and beginning the first stage in restoration. Cool season burns were recommended every two years to reduce fuels sufficiently for growing season burns. Following three cool season burn cycles, burns would be conducted once every three years during the early to mid-growing season to increase mortality in understory hardwood saplings.

Fuel loading (Mg ha\(^{-1}\)) was calculated using Excel software. ANOVA and paired t-tests were performed to test for significant differences in pre- and post-burn fuel loads and vegetation in SPSS Base 10.0 (SPSS Inc. 1999). Exploratory analysis was conducted on data in PC-ORD (McCune & Mefford 1999) using twinspan, Detrended Correspondence Analysis (DCA) and graphing the DCA. DCA was designed for ecological data sets. It is based on samples and species, and ordinates both simultaneously (McCune & Mefford 1999).

Paired t-tests were conducted in Excel on overstory and sapling vegetation to determine differences in standing dead vegetation before and after the burns. Morisita’s index of similarities was conducted on seedling, shrub and herbaceous communities to determine differences in composition before and after the burns (Morisita 1959). Morisita’s index was formulated as follows:

\[
C_M = \frac{2 \sum X_i Y_i}{(S_A + S_B)N_A N_B}
\]
Where: \( X_i = \) Number of species \( i \) in community \( A \)

\( Y_i = \) Number of species \( i \) in community \( B \)

\[ N_A = \sum X_i \]

\[ N_B = \sum Y_i \]

\[ S_A = \frac{\sum [X_i(X_i - 1)]}{N_A(N_A - 1)} \]

\[ S_B = \frac{\sum [Y_i(Y_i - 1)]}{N_B(N_B - 1)} \]

**RESULTS AND DISCUSSION**

Fuel loading results for all parks combined in 1999 (before burning) and 2000 (after burning), indicated a statistically significant reduction in one-hour fuels in burn plots in 2000; however, the actual difference was only 0.05 Mg ha\(^{-1}\). This is not ecologically significant. There was also a statistically significant reduction in ten-hour fuels in the control plots, while there was no change in the burn plots (Table 1).

The only statistically significant difference in hundred- or thousand-hour fuels was an increase in thousand-hour fuels in control plots (Table 1). Larger fuels may have increased due to drought-stressed trees dying and falling.

For all parks combined, \( O_i \) and \( O_e \) horizons' combined weight decreased significantly \((t = 5.182, P < 0.001)\) in the burn plots while it did not in the control plots (Table 2). The actual decrease in the burn plots was 0.98 Mg ha\(^{-1}\). There was also a statistically significant decrease in depth of \( O_i \) and \( O_e \) combined in the burn plots \((t = 2.074, P < 0.05)\), while there was a significant increase in the control plots \((t = 6.641, P < 0.001)\)(Table 2).

Tiles recovered from the burns indicated weak burns at all parks, with Mission Tejas generally burning hotter than Tyler and Village Creek. Tiles showed no effect from the heat of the burns at the 61 cm (2 ft) level in any plot. One tile at Mission Tejas indicated 93°C at the 30 cm
Table 1. Mean fuel loads and paired t-test results for fuels in 1999 (pre-burn) and 2000 (post-burn) in Mission Tejas, Tyler and Village Creek State Parks combined.

<table>
<thead>
<tr>
<th>Plot type</th>
<th>Measurement</th>
<th>One-hour</th>
<th>Ten-hour</th>
<th>Hundred-hour</th>
<th>Thousand-hour</th>
<th>Total</th>
</tr>
</thead>
<tbody>
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<td>Burn</td>
<td>1999 fuel load (Mg ha(^{-1}))</td>
<td>0.29</td>
<td>1.78</td>
<td>1.81</td>
<td>1.63</td>
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</tr>
<tr>
<td></td>
<td>(n = 60, df = 59)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000 fuel load (Mg ha(^{-1}))</td>
<td>0.24</td>
<td>1.58</td>
<td>2.49</td>
<td>2.42</td>
<td>6.68</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>0.05</td>
<td>0.19</td>
<td>-0.68</td>
<td>-0.79</td>
<td>-1.15</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>0.15</td>
<td>2.17</td>
<td>3.73</td>
<td>4.88</td>
<td>5.52</td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>2.453</td>
<td>0.687</td>
<td>-1.406</td>
<td>-1.254</td>
<td>-1.608</td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>0.017</td>
<td>0.495</td>
<td>0.165</td>
<td>0.215</td>
<td>0.113</td>
</tr>
<tr>
<td>Control</td>
<td>1999 fuel load (Mg ha(^{-1}))</td>
<td>0.31</td>
<td>2.25</td>
<td>1.74</td>
<td>2.55</td>
<td>6.84</td>
</tr>
<tr>
<td></td>
<td>(n = 36, df = 35)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000 fuel load (Mg ha(^{-1}))</td>
<td>0.24</td>
<td>1.01</td>
<td>2.04</td>
<td>6.20</td>
<td>9.50</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
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<td>1.23</td>
<td>-0.30</td>
<td>-3.64</td>
<td>-2.50</td>
</tr>
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<td>0.28</td>
<td>1.60</td>
<td>3.30</td>
<td>9.58</td>
<td>10.04</td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>1.518</td>
<td>4.610</td>
<td>-0.553</td>
<td>-2.282</td>
<td>-1.584</td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>0.138</td>
<td>&lt;0.001</td>
<td>0.584</td>
<td>0.029</td>
<td>0.122</td>
</tr>
</tbody>
</table>

Table 2. Mean measurements in 1999 and 2000 and paired t-test results for O\(_i\) and O\(_e\) combined and O\(_a\) horizons in Mission Tejas, Tyler and Village Creek State Parks combined.

<table>
<thead>
<tr>
<th>Plot depth type</th>
<th>Measurement</th>
<th>O(_i) and O(_e) weight (Mg ha(^{-1}))</th>
<th>O(_i) and O(_e) depth (cm)</th>
<th>O(_a) (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burn</td>
<td>1999</td>
<td>2.990</td>
<td>1.348</td>
<td>1.431</td>
</tr>
<tr>
<td></td>
<td>(n* = 60, df = 59)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>2.015</td>
<td>1.203</td>
<td>1.353</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>0.976</td>
<td>0.145</td>
<td>0.077</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.409</td>
<td>0.542</td>
<td>0.550</td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>5.182</td>
<td>2.074</td>
<td>1.084</td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>&lt;0.001</td>
<td>0.042</td>
<td>0.283</td>
</tr>
<tr>
<td>Control</td>
<td>1999</td>
<td>3.716</td>
<td>1.492</td>
<td>1.571</td>
</tr>
<tr>
<td></td>
<td>(n = 36, df = 35)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td>3.480</td>
<td>2.196</td>
<td>1.600</td>
</tr>
<tr>
<td></td>
<td>Mean difference</td>
<td>0.236</td>
<td>-0.703</td>
<td>-0.029</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>1.664</td>
<td>0.636</td>
<td>0.742</td>
</tr>
<tr>
<td></td>
<td>t</td>
<td>0.850</td>
<td>-6.641</td>
<td>-0.234</td>
</tr>
<tr>
<td></td>
<td>Significance</td>
<td>0.401</td>
<td>&lt;0.001</td>
<td>0.817</td>
</tr>
</tbody>
</table>

* n = 56 for O\(_i\) and O\(_e\) weight in the burn plots, df = 55 for O\(_i\) and O\(_e\) weight in the burn plots.

(1 ft) level, while the others recorded no effect. At ground level, tiles indicated a range of intensities from 0°C to 538°C, with Mission Tejas averaging 293°C, Tyler averaging 149°C, and Village Creek averaging 45°C. At the subground level Mission Tejas averaged 197°C and Tyler
averaged 13°C, while tiles at Village Creek recorded no effect. This level of intensity could leave quite a bit of the O horizon and downed woody fuels unburned. After the fires, most surface fuels appeared charred but unconsumed.

It appears the burns did not fully reach the objective of reducing fuel loads. The only ecologically important effects were the decreases in weight and depth of the Oj and Oe horizons in the burn plots. The loss in weight from 1999 to 2000 was 0.98 Mg ha⁻¹, and the difference in depth between the burn and control plots in 2000 was 0.85 cm. These differences were possibly enough to affect the viability of seedlings or herbaceous plants.

**Vegetation**

*Mission Tejas State Historical Park.*—With Axis 1 of the DCA graph representing decreasing time since prior disturbance, one plot was separated to the far right of the other plots in most vegetation classes because it had been burned in the past. There were no records of how long ago the burn occurred. The authors estimated it to be between five and ten years. The plot was very thick with loblolly saplings ranging between one and three inches in diameter.

In both 1999 and 2000, the overstory of Mission Tejas plots was dominated by shortleaf pine followed by sweetgum and loblolly pine. There was not a statistically significant change in number of dead standing overstory or sapling trees from 1999 to 2000. Saplings were dominated by shortleaf and loblolly pines, followed by white oak.

Morisita’s similarity index showed relatively high similarity in composition of seedlings, 50 m shrub and herbaceous transects, shrub belts and herbaceous frames between burn and control plots in 1999 and 2000 (Table 3). They indicated little to no overall effect in these populations from the prescribed burn. Authors believe results would have indicated greater changes in composition had the burns been more severe.

In the seedlings class, loblolly pine, white oak and Southern red oak (*Quercus falcata* Michx.) were common. Sassafras (*Sassafras albidum* (Nutt.) Nees) was absent from the burn plots in 1999, while it was present to either a moderate or heavy degree in 2000.
Table 3. Morisita’s similarity index results for plot comparisons at Mission Tejas, Tyler and Village Creek State Parks pre- (1999) and post-burn (2000).

<table>
<thead>
<tr>
<th>Park</th>
<th>Plots compared</th>
<th>Seedlings</th>
<th>50 m shrub and herbaceous transects</th>
<th>Shrub belts</th>
<th>Herbaceous frames</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mission Tejas</td>
<td>Pre-burn: burn vs. control</td>
<td>0.93</td>
<td>0.61</td>
<td>0.76</td>
<td>0.69</td>
</tr>
<tr>
<td></td>
<td>Post-burn: burn vs. control</td>
<td>0.89</td>
<td>0.94</td>
<td>0.84</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Burn plots: pre- vs. post-burn</td>
<td>1.00</td>
<td>0.95</td>
<td>0.88</td>
<td>0.99</td>
</tr>
<tr>
<td></td>
<td>Controls: pre- vs. post-burn</td>
<td>0.97</td>
<td>0.88</td>
<td>0.88</td>
<td>1.20</td>
</tr>
<tr>
<td>Tyler</td>
<td>Pre-burn: burn vs. control</td>
<td>1.02</td>
<td>0.76</td>
<td>0.94</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>Post-burn: burn vs. control</td>
<td>0.92</td>
<td>0.99</td>
<td>0.99</td>
<td>0.95</td>
</tr>
<tr>
<td></td>
<td>Burn plots: pre- vs. post-burn</td>
<td>0.99</td>
<td>0.85</td>
<td>0.96</td>
<td>0.92</td>
</tr>
<tr>
<td></td>
<td>Controls: pre- vs. post-burn</td>
<td>1.02</td>
<td>0.98</td>
<td>0.90</td>
<td>0.96</td>
</tr>
<tr>
<td>Village Creek</td>
<td>Pre-burn: burn vs. control</td>
<td>1.00</td>
<td>1.01</td>
<td>0.86</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Post-burn: burn vs. control</td>
<td>1.00</td>
<td>0.00</td>
<td>0.60</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>Burn plots: pre- vs. post-burn</td>
<td>1.00</td>
<td>0.80</td>
<td>1.02</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>Controls: pre- vs. post-burn</td>
<td>1.01</td>
<td>0.00</td>
<td>0.41</td>
<td>0.00</td>
</tr>
</tbody>
</table>

For the 50 m shrub and herbaceous transect, litter was more commonly intersected than all plant species combined. In the previously burned plot, the transect was dominated by a heavy ground cover of poison ivy, with little room for anything else. Smilax (*Smilax* sp.), Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.), poison ivy, muscadine grape (*Vitis rotundifolia* Michx.) and partridge-berry (*Mitchella repens* L.) were commonly intersected in the other plots.

The 0.5 m wide shrub belts in all plots at Mission Tejas were dominated by poison ivy, smilax and Virginia creeper, with moderate amounts of muscadine grape and American beautyberry. In the herbaceous classification, the only obvious change from 1999 to 2000 was the heavy presence of goldenrod (*Solidago* sp.) in two of the burn plots in 2000. Goldenrod is a common invader species after disturbance, and was not recorded at all in 1999.

This burn was part of the fuel reduction phase described in the burn
plan (Robinson & Blair 1997). Killing or weakening understory shrubs and pine saplings was one goal of the fuel reduction phase. Results indicated no significant changes in overstory, sapling, seedling, shrub or herbaceous populations.

**Tyler State Park.**—The overstory of plots at Tyler State Park was characterized by shortleaf pine and post oak (*Quercus stellata* Wangenh.). There were no significant changes in dead standing overstory trees from 1999 to 2000.

When graphed in DCA, two plots were commonly placed on the right of the rest of the group. Axis 1 represented soil moisture, with decreasing soil moisture to the right of the graph. These two plots were higher in elevation and would have lower soil moisture than the others.

*T*-tests indicated a significant increase in percent of dead saplings in 2000 in the burn plots (*t* = 3.004, *P* = 0.003). In 1999, there were 7.9 percent dead saplings while there were 18.5 percent in 2000. The control plots indicated the opposite trend, although it was not significant statistically. Thus the increase in the burn plots was evidently due to the burn. Saplings were already suffering drought stress and the additional stress of the burn exterminated weaker individuals. Further *t*-tests indicated no significant differences in dbh or height class of saplings from 1999 to 2000, indicating that combined stresses affected saplings of all diameters and heights evenly.

Morisita’s similarity index illustrated very high similarity between seedlings, 50 m shrub and herbaceous transects, shrub belts and herbaceous frames, from 1999 to 2000, even between burn and control plots (Table 3). In the seedlings class, sweetgum and sassafras were most common, followed by Southern red oak, winged elm (*Ulmus alata* Michx.), red maple, flowering dogwood and American elm. Litter was most often recorded in the 50 m shrub and herbaceous transects. In 2000, twinspan separated plots based on the presence of bare ground. No bare ground was recorded in 1999. The presence of it in 2000 could have been a result of the prescribed burn removing the O horizon.

There were some changes in shrub belt data from 1999 to 2000 in Tyler State Park. Muscadine grape, poison ivy and smilax were common. American beautyberry was absent in 1999, while there was a heavy presence of it in one plot in 2000 that had burned very hot, as
evidenced by char height after the burn. Virginia creeper, which was heavily present in that plot in 1999, was absent in 2000. Longleaf uniola was common in the herbaceous frames.

The 10.6 percent increase in dead saplings appears to be the only significant difference in vegetation. The burn plan (Sparks 1999a) called for increasing herbaceous species, reducing brush species and enhancing species diversity and richness. None of these objectives were reached. The burn was not hot enough to accomplish these goals.

**Village Creek State Park.**—The overstory of Village Creek was characterized by longleaf pine, southern red oak, and sweetgum. Plots closest to the creek were separated from the others in twinspan because they contained river birch, commonly found in wet soils and stream-banks, and Southern magnolia (*Magnolia grandiflora* L.), also common in moist valleys (Little 1980). They also contained lesser amounts of Southern red oak than did other plots, which is more commonly found in dry, sandy loams (Little 1980). When graphed, DCA Axis 1 represented increasing soil moisture in both years in most vegetation classes. *T*-tests indicated no significant changes in standing dead overstory trees.

In saplings, yaupon and redbay were dominant. *T*-tests indicated a significant increase in the number of dead saplings in the burn plots from 1999 to 2000, 12.6 to 19.6 percent, respectively (*t* = 2.286, *P* = 0.023). There was only a slight increase in the control plots, from 12.8 to 13.9 percent. This illustrated a cumulative effect within the burn plots of the drought and the burn combined. There were no significant differences in dbh and height class between 1999 and 2000, illustrating that combined impacts of fire and drought affected all sizes evenly.

Chinese tallowtree was becoming increasingly common in the sapling and seedling stages at Village Creek. It is a native species of China, which has been widely planted as an ornamental in the U.S., because of its vivid fall colors. Seedlings less than one foot tall were omnipresent in areas that were typically wet, but dry due to drought. Chinese tallowtree is hardy, common in sandy soils along streams and grows quickly into thickets (Little 1980). It has the potential to overtake natural vegetation in many areas of the park if left unmanaged.

Morisita’s similarity index reflected nearly exact similarities in
seedling composition between all control and burn plots in both years (Table 3). The burn appeared to have no effect on composition of seedlings. This was not surprising considering the wet condition of the fuels during the burn.

On the shrub and herbaceous transects, litter dominated intercepts on all plots. There were more species of vegetation, and vegetation occurred more often in 1999 than 2000. Although a burn could cause a reduction in shrub species, even herbaceous species, such as little bluestem and a carex sedge (*Carex joorii* Bailey) were also reduced. This is more indicative of drought effects than those of prescribed burning.

Morisita’s similarity index indicated a high degree of similarity between burn and control plots in 1999 (Table 3). However, in 2000, every hit along transects within control plots contacted no vegetation, only litter. This resulted in 0.00 similarity between burns and controls in 2000, and controls in 1999 and 2000. The lack of brush and herbaceous vegetation in the control plots was due to the sustained drought. Village Creek is the northern boundary of the park. The creek often floods in the winter and spring and cypress swamps are present near both the control and the burn units. Because of the drought, the yearly flooding had not occurred in 1999 or 2000; the swamps were dry, and vegetation severely affected.

There were also decreases in the total number of shrub belt species and the numbers recorded within species from 1999 to 2000. The drought appeared to play an important factor from the first year to the next. Some species increased in certain plots while decreasing in other plots, with other species exhibiting opposite responses in those same plots. This is indicative of too few resources. The species with the firmer hold on an area won out.

Morisita’s index also indicated a cumulative effect of the drought and the burn in Village Creek’s shrub belt composition (Table 3). Oddly, the highest rating (1.02) was received by the similarity in the burn plots between 1999 and 2000, indicating no effect on composition by the burn.

The effect of prolonged drought was also evident in the herbaceous frames. In both years, the majority of herbaceous frames were empty.
in all plots. Morisita's similarity index resulted in all comparisons receiving either 0.00 or a low rating (Table 3). This was due to the total lack of herbaceous vegetation in many of the frames in 2000.

At Village Creek the only significant effect of the burn on vegetation was in the percent of dead saplings. The increase, seven percent, in the burn plots was six percent greater than in the control plots. The objectives of encouraging longleaf seedlings, herbaceous species, and increasing species richness and diversity were not met.

CONCLUSIONS

Compared to forests with long-interval, high-severity fire regimes, characterized by stand replacing fires, forests with low- to moderate-severity regimes, characterized by low-intensity surface fires may experience greater adverse effects from high intensity wildfires because they are not adapted to them. Generally, these forests adapted to low-intensity surface fires are more adversely affected by fire suppression and other human influences following European settlement. Active fire seasons occur at more frequent intervals than in long-interval types, due to longer fire seasons, higher average temperatures, and exposure to more potential ignitions during a given fire season. They have missed more fire cycles than longer interval fire regimes, and are generally in greater need of wildfire hazard reduction and restoration of ecological integrity. Wildfires in these areas not only cause more detrimental ecological effects, but they pose great risks to firefighters and property.

It is anticipated with most prescribed burning programs, that the resulting post-fire landscape will have significantly reduced fuel loads and reduced risks of detrimental wildfires. If the post-fire landscapes are also attractive to those who influence policy, positive social benefits can be anticipated as well.

The primary goal of each of these burns was to reintroduce or establish prescribed burning in these parks to further this mission. That objective was met. Park staffs were introduced to the duties, dangers and special considerations necessary with conducting prescribed burns. Each time they are performed by park staff, burns should become less stressful and more efficient.

This short-term project has determined that future burns must be more
intense to meet the fuel loads and vegetation goals outlined in the burn plans. This will require a great deal of cooperation and preparedness from park staff. The window of opportunity to conduct a burn with the desired outcomes may be quite small in any given year. Fuel moisture, wind direction and speed, ambient temperature and capable staff availability must all be ideal to conduct a burn. Once the natural resources coordinator (NRC) has identified an area to be burned it is the responsibility of the park staff to prepare and maintain it in a ready condition.

Initially, dormant season burns should be conducted every two years to reduce fuel loads sufficiently to initiate early to late spring burns. This will require at least two more cool season burns of greater intensity than the burns presently studied. Spring burns occurring every three years will establish a vegetation restoration phase. After a diverse herbaceous layer and open understory have been established, a maintenance phase of burning every five to eight years, depending on desired vegetation, can begin (DellaSala & Frost 2001; Manley et al. 2001).

In years with inadequate prescribed fire windows due to extreme drought or flooding, prescribed burning should not be undertaken. It is too expensive and inefficient to extract employees from their normal duties, and use expensive tools, trucks and ATVs to accomplish so little ecologically. However, TPWD personnel must be willing to take risks based on the best available knowledge. Increasingly, scientific information points to the necessity of fire in maintaining sustainable, healthy forests in the Southeast. Being too cautious could be just as detrimental to the forest as an escaped prescribed fire. The risks of damage from wildfire, disease, insects and overcrowding are increased when prescribed fire is put off another year in hopes of better burning conditions. Fire exclusion will ultimately result in a shift from a nonlethal understory fire regime to a stand-replacement regime accompanied by changes in composition and diversity.

In Texas, county judges are responsible for issuing burn bans, even those with little ecological experience on which to rely. Ideally, a relationship should be fostered between the NRC and county judges issuing the bans. Judges are accustomed to making decisions based on facts and the good of the whole, rather than emotion. They should be capable of understanding the importance of fire on the landscape and the
precautions taken to keep prescribed burns contained. These parks, particularly Village Creek, would have burned naturally during very dry periods. To be forced to adhere to burn bans during these times greatly reduces the restorative powers of prescribed burning. The judges have the authority to allow TPWD to burn for ecological reasons during a burn ban.

In this instance, had TPWD not been bound by the burn bans, burns could have been conducted when fuels were more dry. The failure to reach the objective of reducing fuels in the parks was a direct result of waiting until after a rain event occurred to burn.

Long-term interdisciplinary research projects are necessary to quantify the ecological effects, and economic and social trade-offs of prescribed burning. Only through long-term research may it be determined which natural fire functions can be emulated with prescribed burning, which are irreplaceable, and the implications for management.

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LITERATURE CITED


http://www.tpwd.state.tx.us/park/tyler/tyler.htm (12/18/00).


http://www.tpwd.state.tx.us/park/village/village.htm (12/18/00).


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THE VASCULAR FLORA OF WINDHAM PRAIRIE, POLK COUNTY, EAST TEXAS

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Abstract.—The flora and edaphic conditions are described from Windham Prairie (an isolated calcareous prairie) in Polk County of east Texas. Two hundred and forty-two species of vascular plants representing 182 genera are reported. The soils of this area are neutral to alkaline and very high in calcium.

North American prairies are among the best studied and most endangered plant associations in the world (Diamond et al. 1987; Kucera 1992; Noss et al. 1995; Sims & Risser 2000). In Texas, studies have concentrated on remnants of the once vast prairies of the central and coastal regions of the state (Smeins & Diamond 1983; 1986; Smeins et al. 1992; Diamond & Smeins 1988; 1993; Diggs et al. 1999).

However, there is a type of prairie in the east Texas pineywoods region that has received virtually no ecological or floristic attention. These are the small, scattered or "isolated" calcareous prairies which are often only a few acres in size. Detailed floristic descriptions of isolated prairies have been made in Arkansas, Louisiana and states eastward (Foti 1989; MacRoberts & MacRoberts 1996; 1997; MacRoberts et al. in press; Moran et al. 1997; Leidolf & McDaniel 1998;), but not in Texas (Jordan 1973; 1977; Diamond et al. 1987; Carr 1993).

The purpose of this study was to identify the vascular flora and determine the edaphic conditions of this east Texas isolated prairie.

STUDY SITE AND METHODS

Windham Prairie is located at the intersection of Long Wolf and Windham roads about 8 km south of Livingston in Polk County, Texas. The prairie area measures between 2 to 3 ha within a property of approximately 22 ha. owned by Peebles Family Ltd Partnership. The prairie is a grassy opening with a few scattered shrubs and trees surrounded by typical east Texas pine forest. The topography is gently.
rolling upland located on the Fleming Formation with exposed sandstone outcrops on lower slopes of the prairie. The elevation is 50 to 60 m above sea level. The soil is Wiergate-Burkeville calcareous clay that is gravelly, thin and well drained with a high shrink-swell potential and slow permeability (McEwen et al. 1987).

Annual precipitation is about 125 cm and is fairly evenly distributed through the year. The climate is humid with a mean annual temperature of about 20°C. The summers are long and hot with temperatures rising to 38°C; this, combined with short droughts, translates into very hot and dry conditions especially in open areas. Under drought conditions the soils dry, forming wide cracks. When wet, the soil is very sticky. Winters are short and mild with temperatures occasionally falling to freezing but there are few days of frost.

Windham Prairie has been disturbed. Parts are currently grazed but the main portion has not been grazed for at least a decade. There is no record of it having been burned or plowed. Bothiochloa bladhii is persisting in one section where it was planted for erosion control. There is severe erosion, notably in the vicinity of a now abandoned oil well, with the black topsoil layer totally absent in places. There is a stock pond dug into a small portion of the upper prairie slope, which accounts for the presence of aquatic species on the checklist.

Surveys were made monthly between March and December 2000, and again in February and April 2001. Voucher specimens were deposited in the Spring Branch Science Center Herbarium (SBSC). Soil samples from the upper 15 cm were collected from widely scattered sites within the prairie and analyzed by A & L Laboratories, Memphis, Tennessee.

Results

This study reports the presence of 242 species of vascular plants, representing 182 genera and 64 families, from Windham Prairie:

FAMILY ACANTHACEAE
*Ruellia humilis* Nutt.

FAMILY ACERACEAE
*Acer saccharum* Marsh. var. *floridanum* (Chapm.) Small & Heller

FAMILY AGAVACEAE
*Manfreda virginica* (L.) Salisb. ex Rose

FAMILY ANACARDIACEAE
*Rhus copallinum* L.
*Toxicodendron radicans* (L.) Kuntze
FAMILY APIACEAE
Chaerophyllum tainturieri Hook.
Cyclospermum leptophyllum (Pers.) Sprague ex Britt. & Wilson
Daucus pusillus Michx.

FAMILY Aquifoliaceae
Ilex decidua Walt. var. decidua
Ilex opaca Aiton
Ilex vomitoria Aiton

FAMILY ARECACEAE
Sabal minor (Jacq.) Pers.

FAMILY ASCLEPIADACEAE
Asclepias viridiflora Raf.
Matelea gonocarpa (Walt.) Shinners

FAMILY ASTERACEAE
Ambrosia artemisiifolia L.
Ambrosia trifida L.
Arnoglossum plantagineum Raf.
SYN = Cacalia plantaginea (Raf.) Shinners
Symphyotrichum drummondii (J. Lindley) Nesom var. texanum (Burgess) Nesom
SYN = Aster drummondii Lindl. var. texanus (Burgess) A. Jones
Symphyotrichum dumosum (L.) Nesom
SYN = A. dumosus L.
Symphyotrichum laeve (L.) A. & D. Love var. purpuratum (Nees) Nesom
SYN = A. laevis L. var. purpuratus (Nees) A. G. Jones
Symphyotrichum lateriflorum (L.) A. & D. Love
SYN = A. lateriflorum (L.) Britton
Symphyotrichum racemosum (S. Elliot) Nesom
SYN = A. fragilis Willd.
Symphyotrichum oolentangiense (Riddell) Nesom
SYN = A. oolentangiensis Riddell
Symphyotrichum subulatum (Michx.) Nesom
SYN = A. subulatus Michx.
Baccharis halimifolia L.
Brickellia eupatorioides (L.) Shinners var. eupatorioides
Evax verna Raf.
Cirsium horridulum Michx.
Conyza canadensis (L.) Cronq.
Coreopsis lanceolata L.
Coreopsis tinctoria Nutt. var. tinctoria
Croptilon divaricatum (Nutt.) Raf.
Erigeron strigosus Muhl. ex Willd.
Eupatorium capillifolium (Lam.) Small
Eupatorium compositifolium Walt.
Gamochaeta falcata (Lam.) Cabrera
SYN = Gnaphalium falcatum Lam.
Grindelia lanceolata Nutt. var. lanceolata
Helenium amarum (Raf.) H. Rock var. amarum
Heterotheca subaxillaris (Lam.) Britt. & Rusby
(including H. latifolia Buckl.)
Iva angustifolia DC.
Iva annua L.
Krigia cespitosa (Raf.) Chambers f. cespitosa
Lactuca canadensis L.
Liatris mucronata DC.
Plucheia camphorata (L.) DC.
Pyrrhopappus pauciflorus (D. Don) DC.
SYN = P. multicaulis DC.
Ratibida columnifera (Nutt.) Woot. & Standl.
Rudbeckia hirta L.
Rudbeckia missouriensis Boynt. & Beadle
Solidago canadensis L.
Xanthium strumarium L.

FAMILY BETULACEAE
Ostrya virginiana (Mill.) K. Koch

FAMILY BIGNONIACEAE
Bignonia capreolata L.
Campsis radicans (L.) Seem. ex Bureau

FAMILY BORAGINACEAE
Heliotropium indicum L.
Heliotropium procumbens Mill.
Heliotropium tenellum (Nutt.) Torr.
Onosmodium bejariense A. DC. var. bejariense

FAMILY BUDDLEJACEAE
Polypremum procumbens L.

FAMILY CAMPANULACEAE
Triodanis perfoliata (L.) Nieuw. var. biflora (R.& P.) Bradley
Triodanis perfoliata (L.) Nieuw. var. perfoliata

FAMILY CAPRIFOLIACEAE
Lonicera japonica Thunb.
Lonicera sempervirens L.
Viburnum rufidulum Raf.

FAMILY CELASTRACEAE
Euonymus americana L.

FAMILY CONVOLVULACEAE
Dichondra carolinensis Michx.
Ipomoea cordatotriloba Dennstedt var. cordatotriloba

FAMILY CORNACEAE
Cornus drummondii C. A. Mey.
Cornus florida L.

FAMILY CUPRESSACEAE
Juniperus virginiana L. var. virginiana

FAMILY CUSCUTACEAE
Cuscuta indecora Choisy var. longisepala Yuncker
Cuscuta pentagona Engelm. var. pentagona

FAMILY CYPERACEAE
Carex cherokeensis Schwein.
Carex microdonta T. & H.
Cyperus odoratus L.
Cyperus virens Michx.
Eleocharis montevidensis Kunth
Fimbristylis autumnalis (L.) Roem. & Schult.
Scleria oligantha Michx.

FAMILY EBENACEAE
Diospyros virginiana L.

FAMILY EUPHORBIAEAE
Croton monanthogynus Michx.
Euphorbia bicolor Engelm. & Gray
Euphorbia maculata L.
SYN = Chamaesyce maculata (L.) Small
Euphorbia nutans Lag.
SYN = C. nutans (Lag.) Small
Euphorbia serpens Kunth
SYN = C. serpens (Kunth) Small
Euphorbia spathulata Lam.

FAMILY FABACEAE
Acacia angustissima (Miller) Kuntze var. hirta (Nutt.) B. L. Robinson
Albizia julibrissin Durazzini
Astragalus distortus T. & H. var. engelmannii (Sheld.) M. E. Jones
Cercis canadensis L.
Chamaecrista fasciculata (Michx.) Greene
Crotalaria sagittalis L.
Dalea compacta Sprengel var. compacta
Dalea compacta Sprengel var. pubescens (A. Gray) Barneby
Dalea multiflora (Nutt.) Shinners
Desmanthus illinoensis (Michx.) MacM.
Desmodium ciliare (Willd.) DC.
Desmodium paniculatum (L.) DC.
Erythrina herbacea L.
Galactia volubilis (L.) Britt.
Glottidium vesicarium (Jacq.) Harper
SYN = Sesbania vesicaria (Jacq.) Ell.
Indigofera miniata Ort.
Lespedeza procumbens Michx.
Lespedeza virginica (L.) Britt.
Medicago lupulina L.
Mimosa strigillosa T.& G.
Neptunia pubescens Benth.
Rhynchosia minima (L.) DC.
Sesbania drummondii (Rydb.) Cory
Sesbania herbacea (P. Mill) McVaugh
SYN = Sesbania exaltata (Raf.) Cory
Strophostyles umbellata (Willd.) Britt.
Vicia ludoviciana Nutt. ssp. ludoviciana
Vicia sativa L.

FAMILY FAGACEAE
Quercus nigra L.
Quercus shumardii Buckl.

FAMILY GENTIANACEAE
Centarium pulchellum (Sw.) Druce

FAMILY GERANIACEAE
Geranium carolinianum L.

FAMILY HAMAMELIDACEAE
Liquidambar styraciflua L.

FAMILY HYPERICACEAE (CLUSIACEAE)
Hypericum hypericoides (L.) Crantz.

FAMILY IRIACEAE
Sisyrinchium rosulatum Bickn.
(including the yellow-flowered S. exile Bickn.)
FAMILY JUGLANDACEAE
*Carya texana* Buckl.
*Juglans nigra* L.

FAMILY JUNCACEAE
*Juncus marginatus* Rostk.
*Juncus validus* Cov.

FAMILY LAMIACEAE
*Hedeoma hispidum* Pursh
*Monarda citriodora* Cerv. ex Lag. var. *citriodora*
*Monarda fistulosa* L.
*Prunella vulgaris* L.
*Salvia azurea* Lam. var. *grandiflora* Benth.
*Salvia lyrata* L.
*Scutellaria cardiophylla* Engelm. & Gray
*Scutellaria parvula* Michx. var. *parvula*

FAMILY LILIACEAE
*Allium stellatum* Nutt. ex Ker-Gawler
*Hypoxis* sp.
*Nothoscordum bivalve* (L.) Britt.

FAMILY LOGANIACEAE
*Gelsemium sempervirens* (L.) Ait. f.
*Mitreola petiolata* (J. F. Gmel.) T. & G.

FAMILY MYRICACEAE
*Myrica cerifera* L.
SYN = *Morella cerifera* (L.) Small

FAMILY NAJADACEAE
*Najas guadalupensis* (Spreng.) Magnus

FAMILY OLEACEAE
*Forestiera ligustrina* (Michx.) Poir.
*Fraxinus americana* L.
*Ligustrum lucidum* Ait. f.
*L. sinense* Lour.

FAMILY ONAGRACEAE
*Ludwigia glandulosa* Walt.
*Oenothera laciniata* Hill
*Oenothera speciosa* Nutt.

ORCHIDACEAE
*Spiranthes tuberosa* Raf.
FAMILY OXALIDACEAE
_Oxalis corniculata_ L.
   including _O. dillenii_ Jacq.

FAMILY PINACEAE
_Pinus echinata_ Mill.
_Pinus taeda_ L.

FAMILY PLANTAGINACEAE
_Plantago aristata_ Michx.
_Plantago rhodosperma_ Dcne.
_Plantago virginica_ L.

FAMILY PLATANACEAE
_Platanus occidentalis_ L.

FAMILY POACEAE
_Agrostis hyemalis_ (Walt.) B.S.P.
_Andropogon gerardii_ Vitman
_Andropogon glomeratus_ (Walt.) B.S.P.
_Andropogon virginicus_ L. var. _virginicus_
_Aristida longespica_ Poir. var. _geniculata_ (Raf.) Fern.
_Aristida oligantha_ Michx.
_Aristida purpurascens_ Poiret
_Bothriochloa bladhii_ (Retz.) S. T. Blake
_Bothriochloa ischaemum_ (L.) Keng. var. _songarica_ (Fish. & Mey)
   Celarier & Harlan
_Bothriochloa longipaniculata_ (Gould) Allred & Gould
_Bouteloua curtipendula_ (Michx.) Torr.
_Bouteloua hirsuta_ Lag.
_Briza minor_ L.
_Bromus japonicus_ Thunb. ex. J. Murray
_Chasmanthium laxum_ (L.) Yates var. _laxum_
_Chasmanthium laxum_ (L.) Yates var. _sessiliflorum_ (Poir.) Wipff & S. D. Jones
_Cynodon dactylon_ (L.) Pers.
_Dactyloctenium aegyptium_ (L.) Beauv.
_Dichanthelium acuminatum_ (Sw.) Gould & Clark var. _acuminatum_
_Digitaria ciliaris_ (Retz.) Koel.
_Elymus virginicus_ L.
_Eragrostis secundiflora_ Presl ssp. _oxylepis_ (Torr.) S. D. Koch
_Lolium perenne_ L.
_Limnocharis arkansana_ (Nutt.) L. H. Dewey
_Melica mutica_ Walt.
_Muhlenbergia capillaris_ (Lam.) Trin.
Nassella leucotricha (Trin. & Rupr.) Pohl
  SYN = Stipa leucotricha Trin. & Rupr.

Panicum dichotomiflorum Michx.
Panicum virgatum L.
Paspalum dilatatum Poir.
Paspalum langei (Fourn.) Nash
Paspalum notatum Flugge
Paspalum plicatum Michx.
Paspalum pubiflorum Rupr. ex Fourn.
Paspalum urvillei Steud.
Phalaris caroliniana Walt.

Piptochaetium avenaceum (L.) Parodi

Poa annua L.

Setaria parviflora (Poiret) Kerguelen
  SYN = S. geniculata (Lam.) Beauv.

Schizachyrium scoparium (Michx.) Nash
Sorghastrum nutans (L.) Nash
Sorghum halepense (L.) Pers.

Sphenopholis obtusata (Michx.) Scribn.
Sporobolus compositus (Poiret) Merrill var. compositus
Trisetum interruptum Buckl.

FAMILY POLYPODIACEAE

Pleopeltis polypodioides (L.) Andrews & Windham var. michauxianum
(Weath.) Andrews & Windham

FAMILY PRIMULACEAE

Anagallis arvensis L.

FAMILY RANUNCULACEAE

Anemone berlandieri Pritz.

Delphinium carolinianum Walt. ssp. vimineum (D. Don) M. Warnock

FAMILY RHAMNACEAE

Berchemia scandens (Hill) K. Koch

Rhamnus caroliniana Walt.
  SYN = Frangula caroliniana (Walt.) Gray

FAMILY ROSACEAE

Crataegus marshallii Eggston
Crataegus spathulata Michx.
Prunus angustifolia Marsh.
Prunus caroliniana (Mill.) Aiton.
Pyrus calleryana Dcne
Rubus argutus Link
SYN = R. louisianus Berger

Rubus trivialis Michx.

FAMILY RUBIACEAE
Diodia virginiana L.
Galium pilosum Aiton
Galium virgatum Nutt.
Houstonia pusilla Schoepf
  SYN = Hedyotis crassifolia Raf.
Stenaria nigricans (Lam.) Terrell
  SYN = Hedyotis nigricans (Lam.) Frosb.

RUTACEAE
Zanthoxylum clava-herculis L.

FAMILY SALICACEAE
Populus deltoides Bart. ex Marsh.
Salix nigra Marsh. var. nigra

FAMILY SAPINDACEAE
Sapindus saponaria L. var. drummondii (Hook. & Arn.) L. Benson

FAMILY SAPOTACEAE
Sideroxylon lanuginosum Michx.
  SYN = Bumelia lanuginosa (Michx.) Pers.

FAMILY SCROPHULARIACEAE
Agalinis purpurea (L.) Penn.
Leucospora multifida (Michx.) Nutt.
Mecardonia acuminatum (Walt.) Small
Penstemon cobaea Nutt.
Veronica arvensis L.

FAMILY SMILACAEAE
Smilax bona-nox L

FAMILY TILIACEAE
Tilia americana L. var. americana
Tilia americana L. var. caroliniana (Mill.) Castig

FAMILY TYPHACEAE
Typha latifolia L.

FAMILY ULMACEAE
Ulmus alata Michx.
Ulmus crassifolia Nutt.

FAMILY VALERIANACEAE
Valerianella radiata (L.) Dufr. f. parviflora (Dyal) Eggers
FAMILY VERBENACEAE
Callicarpa americana L.
Verbena officinale L. ssp. halei (Small) Barber
Verbena rigida Spreng.
Verbena xutha Lehm.

FAMILY VIOLACEAE
Viola sororia Willd.

FAMILY VITACEAE
Ampelopsis arborea (L.) Koehne
Parthenocissus quinquefolia (L.) Planch.
Vitis cinerea (Engelm.) Engelm. ex Millardet
Vitis mustangensis Buckl.
Vitis rotundifolia Michx.

Grasses, composites and legumes dominated accounting for 45 percent of the species. The soils are neutral to alkaline and very high in calcium (Table 1). They are very similar to prairies in Louisiana (MacRoberts & MacRoberts 1996).

**DISCUSSION**

Windham Prairie is about 80 km east of the once extensive Blackland (Fayette) Prairie and about 60 km north of the Coastal prairies (Smeins & Diamond 1983; Diamond & Smeins 1984). Between Windham Prairie and the Blackland Prairie and the Coastal Prairie are other isolated prairies (Nesom & Brown 1998). On the basis of published (but incomplete) plant lists, Windham Prairie shows strong affinities to the upper clay/clay loam sections of the Fayette Prairie (Smeins & Diamond 1983; Diamond & Smeins 1988) and also to the upland section of the Coastal Prairie (Diamond & Smeins 1984; 1988). This is not surprising considering the close proximity of these prairies and the fact, as pointed out by Diamond & Smeins (1984), that the upland Coastal Prairie and upper clay Fayette Prairie are not distinct but represent a north-south continuum of prairie communities.

Many species rare to east Texas (region I of Hatch et al. 1990) occur in Windham Prairie. They include Symphotrichum oolentangiense, Liatris mucronata, Grindelia lanceolata, Rudbeckia missouriensis, Carex microdonta, Acacia angustissima var. hirta, Dalea compacta var. compacta and D. compacta var. pubescens, Allium stellatum and Penstemon cobaea.

Symphotrichum oolentangiense is mapped in 12 region I counties (Turner et al. in press). Polk county is a new county record. It occurs
Table 1. Soil characteristics of Windham Prairie (OM = organic matter).

<table>
<thead>
<tr>
<th>Sample</th>
<th>pH</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>OM%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7.1</td>
<td>20</td>
<td>153</td>
<td>6361</td>
<td>94</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>7.6</td>
<td>2</td>
<td>226</td>
<td>12502</td>
<td>190</td>
<td>2.3</td>
</tr>
<tr>
<td>3</td>
<td>7.9</td>
<td>7</td>
<td>137</td>
<td>11652</td>
<td>57</td>
<td>0.8</td>
</tr>
<tr>
<td>4</td>
<td>8.0</td>
<td>6</td>
<td>190</td>
<td>14553</td>
<td>93</td>
<td>2.5</td>
</tr>
</tbody>
</table>

widely in Louisiana prairies (Thomas & Allen 1993-1998; MacRoberts & MacRoberts 1996).

*Liatris mucronata* is reported abundant on the Edwards Plateau, the Plains Country, and north-central Texas but rare in east Texas. Polk is one of four counties mapped in region I (Turner et al. in press).

*Grindelia lanceolata* was mapped only in Hardin and Walker counties by Nesom (1990). Turner et al. (in press) mapped two additional counties, San Jacinto and Polk. It is abundant here.

*Rudbeckia missouriensis* is abundant on the site. Specimens of this taxon at SBSC and ASTC are from Polk County. At SBSC there is one additional record from Montgomery County. Turner et al. (in press) mapped it in Walker, Polk and Tyler counties. It also occurs in Louisiana prairies (Thomas & Allen 1993-1998).

*Carex microdonta* is one of the few *Carex* prairie species. Correll & Johnston (1970) consider this species rare in east Texas. Turner et al. (in press) mapped it only in the region I county of San Jacinto. Polk is a new county record. It is common in Louisiana prairies (Thomas & Allen 1993-1998; MacRoberts & MacRoberts 1996).

*Acacia angustissima* var. *hirta* is a small shrub that neither Turner (1959) nor Isely (1998) mapped for central-east Texas. Turner et al. (in press) mapped it in Cherokee and Montgomery counties of region I. This is a new county record. It is rare in Louisiana (Thomas & Allen 1993-1998).

*Dalea compacta* var. *compacta* and *D. compacta* var. *pubescens* are rare in east Texas. *Dalea compacta* var. *compacta* is mapped only in four region I counties including Polk (Turner et al. in press). The Polk Windham Prairie collection of *D. compacta* var. *pubescens* is a new county record. *Dalea compacta* var. *pubescens* is recorded for Louisiana (Thomas & Allen 1993-1998).
Allium stellatum is mapped in five mostly north-central Texas counties (Turner et al. in press). This is the first record for east Texas. It is disjunct from Van Zandt, the nearest mapped county.

Penstemon cobaea is mapped in the region I counties of Montgomery, Walker, Houston, and Anderson (Turner et al. in press). The Windham Prairie record is one of the most eastern Texas stations.

ACKNOWLEDGMENTS

Thanks to Billie L. Turner of the University of Texas at Austin (TEX/LL) for sending distribution maps from his soon to be published Atlas of the Texas Flora. These have helped us to a better understanding of the distribution of some significant Windham Prairie plants. The first author is thankful to the Houston Community College for a sabbatical leave during the spring semester of 2002 which aided the completion of this project.

LITERATURE CITED


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NOTEWORTHY PLANTS ASSOCIATED WITH THE GULF COASTAL BEND OF TEXAS.

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Abstract.—Based on data from fieldwork on northern Padre and Mustang islands in the Coastal Bend region of Texas, 31 species of vascular plants in 19 families are reported as new distribution and occurrence records. Three species (Cakile geniculata, Helianthus debilis subsp. cucumerifolius and Sisyrinchium sagittiferum) represent new additions to the flora of the Coastal Bend region.

In this study, distribution and occurrence of plant species from Mustang Island (Gillespie 1976), northern Padre Island (Negrete et al. 1999) and the Texas Coastal Bend (Jones 1982) were examined. These data were compared to known ranges as well as searches of the literature and local herbaria.

STUDY AREA AND METHODS

Northern Padre Island, east of Corpus Christi, Texas, is the location of Padre Island National Seashore (PINS) and Mustang Island, located north of PINS, is the site of Mustang Island State Park. Both were formed by deposition of sand during the Pleistocene (McAlister & McAlister 1993) and are important barrier islands located in the Coastal Bend region of southeastern Texas. Annual temperatures increase and annual precipitation decreases from north to south down the Texas coast (McAlister & McAlister 1993). Typical habitats found on the islands include coppice dunes, foredunes, barrier flats and tidal flats (Nelson et al. 2000).

Data on distribution and occurrence of species was obtained from fieldwork reported in Negrete et al. (1999) at PINS from 1996-1998 and
Gillespie (1976) at Mustang Island State Park from 1967-1968. This data was compared to ranges and occurrence of species in Jones (1982). Nomenclature of native or naturalized plants was standardized using Jones et al. (1997). Taxa are discussed alphabetically according to class and family. Voucher specimens reported in this study are deposited with the holdings of the Corpus Christi Museum (C.C. Museum), Padre Island National Seashore (PINS), Tarleton State University Herbarium (TAC) and Texas A&M University-Kingsville Herbarium (TAIC).

RESULTS AND DISCUSSION

This analysis resulted in new distribution and occurrence records for 31 species from the Texas Coastal Bend in relation to information currently available in the Flora of the Coastal Bend (Jones 1982). Cakile geniculata, Helianthus debilis subsp. cucumerifolius and Sisyrinchium sagittiferum represent new additions to the flora of the Coastal Bend region. New distribution records for taxa are discussed individually.

CLASS LILIOPSIDA

FAMILY COMMELINACEAE

Commelina erecta L. var. erecta is reported from Mustang Island (Gillespie 1976) and northern Padre Island (Negrete et al. 1999). It is considered common in prairies, openings, stream bottoms and in waste places along roads in the Coastal Bend (Jones 1982). It was found in waste places and barrier flats on northern Padre Island (TAIC N303).

FAMILY CYPERACEAE

Fuirena scirpoidea Michx. occurs in sandy depressions and marshes along the coast from north of Fulton, south of Ingelside, and the King Ranch (Jones 1982). Its range can now be extended to northern Padre Island by the voucher specimen (C.C. Museum 76D457) reported in Negrete et al. (1999).

FAMILY IRIDACEAE

Sisyrinchium sagittiferum Bickn. is found as a part of the flora of
Mustang (Gillespie 1976) and northern Padre Island (Negrete et al. 1999). It is also found in low wet areas in eastern Texas (Correll & Johnston 1970) but has not been previously reported from the Coastal Bend region (Jones 1982). A voucher specimen (PINS 724) was located at the PINS Herbarium.

**FAMILY JUNCACEAE**

*Juncus megacephalus* M. A. Curtis has been reported from a marsh above the beach north of Fulton (Jones 1982) in the Coastal Bend region. The specimen was collected in the barrier flat of PINS (TAC N699) and its range should be extended to northern Padre Island (Negrete et al. 1999).

*Juncus roemerianus* Scheele has been reported from sandy swales on the Aransas National Wildlife Refuge (Jones 1982). Its range can now be extended to northern Padre Island by the voucher specimen (PINS 2484) reported in Negrete et al. (1999).

**CLASS MAGNOLIOPSIDA**

**FAMILY ACANTHACEAE**

*Ruellia corzoi* Tharp & Barkl. is frequent on dry sand and caliche from Mathis to Orange Grove, Alice and Premont (Jones 1982) in the Coastal Bend region. Its range can now be extended to northern Padre Island because of the voucher specimen (PINS 2532) reported in Negrete et al. (1999).

**FAMILY APIACEAE**

*Hydrocotyle umbellata* L. occurs on Mustang (Jones 1982) and northern Padre Island (Negrete et al. 1999). It is locally abundant on damp sands in swales, depressions and around lakes (Jones 1982) in the Coastal Bend region. It has also been reported from Aransas National Wildlife Refuge, north of Rockport, and Welder Wildlife Refuge (Jones 1982). Its range can now be extended to northern Padre Island due to the presence of a voucher specimen (PINS 1390) reported in Negrete et al. (1999).
FAMILY ASTERACEAE

*Croptilon divaricatum* (Nutt.) Raf. is occasional on deep coastal sands and has been reported from south of Ingleside and at Goose Island State Park (Jones 1982). Its range can now be extended to northern Padre Island because of the voucher specimen (TAIC CSP 44) reported in Negrete et al. (1999).

*Helianthus debilis* Nutt. subsp. *cucumerifolius* (Torr. & A. Gray) Heiser is found as part of the flora of northern Padre Island (Negrete et al. 1999) but was not reported as a part of the Coastal Bend flora (Jones 1982). A specimen was collected in the tidal flat of northern Padre Island (TAC N684).

*Helianthus praecox* Engelm. & A. Gray subsp. *runyonii* (Heiser) Heiser occurs in coastal sands in a variety of habitats in the Coastal Bend region (Correll & Johnston 1970; Jones 1982). A voucher specimen (PINS 2364) located in the PINS Herbarium extends the range onto northern Padre Island.

*Palafoxia hookeriana* Torr. & A. Gray occurs on northern Padre Island (Negrete et al. 1999) and has been reported from Rockport and Aransas Pass (Jones 1982). A voucher specimen (PINS 1383) was located in the PINS Herbarium that extends the range onto northern Padre Island.

*Thelesperma nuecense* Turner was reported by Jones (1982) to occur frequently along the mainland coast from Aransas National Wildlife Refuge to Baffin Bay. A voucher specimen (PINS 1348) located in the PINS Herbarium that extends the range onto northern Padre Island.

FAMILY AVICENNIACEAE

*Avicennia germinans* (L.) L. is occasional to locally abundant on moist sandy soils along beaches and on marshy islands at Packery Channel, Harbor Island and the mouth of the Aransas River (Jones 1982). Its range can now be extended to northern Padre Island by the presence of a voucher specimen (PINS 6668) reported in Negrete et al. (1999).

FAMILY BRASSICACEAE

*Cakile geniculata* (Robins.) Millsp. occurs on beaches and sandy
places near the ocean (Correll & Johnston 1970) but was not included in the flora of the Coastal Bend region (Jones 1982). Its range can now be extended to the Coastal Bend region and northern Padre Island by the voucher specimen (TAIC 398) reported in Negrete et al. (1999).

FAMILY CISTACEAE

*Helianthemum georgianum* Chapm. is frequent in sandy oak woods along the coast and is known from woods and pastures on the Welder Wildlife Refuge and south of Refugio (Jones 1982). It has been reported from northern Padre Island (PINS 518) by Negrete et al. (1999) and this extends its range onto the island.

FAMILY CLUSIACEAE

*Hypericum gentianoides* (L.) Britton, Stems & Poggenb. is frequent on coastal sands in swales from Aransas National Wildlife Refuge to Flour Bluff and southward (Jones 1982). It has been reported from northern Padre Island (PINS 2430) by Negrete et al. (1999).

*Hypericum hypercoides* (L.) Crantz subsp. *hypercoides* is frequent on deep coastal sands from Aransas National Wildlife Refuge to Flour Bluff and southward into the Coastal Bend region (Jones 1982). It has been reported from northern Padre Island (PINS 721) by Negrete et al. (1999).

*Hypericum pauciflorum* H.B.K. is occasional on sandy soils in openings, prairies or lowlands of the barrier islands (Jones 1982). It has been reported from the adjacent mainland at the Texas A & M University-Kingsville Biological Station located on Baffin Bay (TAC 29).

FAMILY CUSCUTACEAE

*Cuscuta indecora* Choisy occurs abundantly in the Nueces River bottom near Calallen (Jones 1982). It was reported from northern Padre Island (PINS 885) by Negrete et al. (1999).

FAMILY FABACEAE

*Clitoria mariana* L. is occasional on deep coastal sands southwest of Aransas Pass and west of Flour Bluff (Jones 1982). It has been reported
from northern Padre Island (PINS 2400) by Negrete et al. (1999) and this extends its range onto the island.

*Crotolaria sagittalis* L. was previously reported from the Aransas National Wildlife Refuge to Flour Bluff and southward into the Coastal bend region (Jones 1982). It has been reported from northern Padre Island (PINS 4092) by Negrete et al. (1999) thus extending its range onto the island.

*Dalea obovata* (Torr. & A. Gray) Shinners is frequent on coastal sands from Aransas National Wildlife Refuge to Flour Bluff and southward into the Coastal Bend region (Jones 1982). It was reported from northern Padre Island (PINS 738) by Negrete et al. (1999) extending its range onto the island.

*Erythrina herbacea* L. occurs on Mustang (Gillespie 1976) and northern Padre Island (Negrete et al. 1999). It is frequent on coastal sands from south of Refugio, Aransas National Wildlife Refuge, Flour Bluff and southward into the Coastal Bend region (Jones 1982). This species range can now be extended to northern Padre Island due to the presence of a voucher specimen (PINS 734) reported by Negrete et al. (1999).

*Glottidium vesicaria* (Jacq.) R. M. Harper occurs on damp sands from south of Refugio, Aransas Pass and northeast of Orange Grove (Jones 1982). It has been reported from northern Padre Island (PINS 7748) by Negrete et al. (1999).

**FAMILY FAGACEAE**

*Quercus minima* (Sarg.) Small was reported as frequent on coastal sands from Aransas National Wildlife Refuge to Flour Bluff and southward into the Coastal Bend region (Jones 1982). It has been reported from northern Padre Island (CC Museum 7922) by Negrete et al. (1999).

*Quercus virginiana* Mill. var. *virginiana* is frequent on coastal sands from Aransas National Wildlife Refuge to Baffin Bay (Jones 1982). Its range can now be extended to northern Padre Island (PINS 931) by Negrete et al. (1999).
FAMILY MALVACEAE

*Kosteletzkya virginica* (L.) K. Presl ex A. Gray occurs on moist soil from northeast of Tivoli, Aransas National Wildlife Refuge, north of Rockport, and on Mustang Island (Gillespie 1976; Jones 1982). Its range can now be extended to northern Padre Island (CC Museum 6912) by Negrete et al. (1999).

FAMILY MYRICACEAE

*Morelia cerifera* (L.) Small was reported as frequent on coastal sands from Aransas National Wildlife Refuge to Flour Bluff and southward into the Coastal Bend region (Jones 1982). It has been found on northern Padre Island (PINS 764) as reported by Negrete et al. (1999).

FAMILY POLYGALACEAE

*Polygala incarnata* L. was reported as occasional in moist coastal sands and sandy oak woods northwest of Refugio (Jones 1982). It has been reported from northern Padre Island (TAC N637) by Negrete et al. (1999).

FAMILY POLYGONACEAE

*Polygonella polygama* (Vent.) Engelm. and A. Gray was reported as infrequent in sandy low grounds along the coast from Aransas National Wildlife Refuge to Flour Bluff (Jones 1982). It has been reported from northern Padre Island (PINS 6698 and TAC N637) by Negrete et al. (1999).

FAMILY RUTACEAE

*Thamnosma texana* (A. Gray) Torr. was reported as frequent on dry sand and caliche north and west of Mathis and north of Orange Grove (Jones 1982). It has been reported south of these localities on a rocky hillside at Captain’s Pond in Kingsville, Texas (TAC N281).

ACKNOWLEDGMENTS

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MUTAGENIC ACTIVITY OF IDARUBICIN AND EPIRUBICIN IN THE BACTERIUM SALMONELLA TYPHIMURIUM

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Department of Biology & Health Services
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Abstract.—Idarubicin (structural analogue of daunomycin) and epirubicin (epimer of adriamycin) are two "second-generation" anthracyclines that are widely used in chemotherapy against leukemias and metastatic breast tumors, respectively. This study shows that using the Salmonella Mutagenicity Assay that idarubicin, like daunomycin, can induce frameshift (TA98; 16.1 fold), GC to AT (TA7004; 8.7 fold), and AT to GC base-substitution transition mutations (TA7001; 2.8 fold). Epirubicin, like adriamycin, can also induce frameshift (19.7 fold) and GC to AT transition mutations (14.6 fold) in this assay. Interestingly, epirubicin, but not adriamycin, can induce AT to GC mutations (2.9 fold) in this assay.

Anthracycline antibiotics, primarily daunomycin and adriamycin, have been utilized in clinical practice since the 1960’s and represent one of the most commonly used classes of anticancer drugs against leukemias and solid tissue tumors (reviewed by Sinha & Politi 1990; Hande 1998; Gewirtz 1999; Ogura 2001; Felix 2001). However, these highly active chemotherapeutic agents are also associated with acute cardiotoxic effects and a dose-related cardiomyopathy (reviewed by Hortobagyi 1997; Keefe 2001). Extensive efforts since 1972 have resulted in the replacement of these parent compounds with less toxic "second-generation" structural analogues (reviewed by Arcamone 1984; Carella et al. 1990; Fields & Koeller 1991; Hollingshead & Faulds 1991; Borchmann et al. 1997; Platel et al. 1999). Among these new compounds, 4-methoxy-daunorubicin (idarubicin), a structural analogue of daunomycin, was shown to be effective against acute nonlymphocytic leukemias with reduced cardiotoxic effects in clinical trials (Cersosimo 1992; Bogush & Robert 1996; Andersson et al. 1999; Lee et al. 2001). Similarly, 4'-epidoxorubicin (epirubicin), a 4'-epimer of adriamycin, is now widely used against early and metastatic breast cancers (Ganzina 1983; Weiss 1992; reviewed by Hortobagyi 2000; Razis & Fountzilas 2001; Trudeau & Pagani 2001).

It is known that anthracyclines (particularly the sugar moiety of the compound) can interfere with a number of biochemical and biological
functions in the cell. Several studies strongly suggest that membrane binding and poisoning of topoisomerase II activity are possible modes of action for these anticancer antibiotics (Binaschi et al. 1998; Arcamone et al. 1999; Guano et al. 1999; Zunino et al. 2001). However, numerous studies also suggest that the biological activity of these drugs correlate with DNA binding with a preference to the GC bases (Fenick et al. 1997; Taatjes et al. 1997; Davies et al. 2000; Eaton et al. 2000; Qu et al. 2001). Several studies have demonstrated that anthracyclines are mutagenic in prokaryotic and eukaryotic cells (Marzin et al. 1983; Babudri et al. 1984; Olinski et al. 1997; El-Mahdy & Othman 2000; Mackay et al. 2000; Mackay & Phelps 2001). However, the mutagenicity of anthracyclines has been underestimated in the past, partly since these drugs are only "slightly" mutagenic in microbial assays (Kaldor et al. 1986; Tominaga 1986; Bokemeyer & Schmoll 1995). More recently, however, it has been suggested that the mutagenic properties of anthracyclines during tumor treatment may result in secondary cancers following chemotherapy (Olinski et al. 1997; 1998; Baguley & Ferguson 1998; Vakeva et al. 2000). Thus, it is very important to fully characterize both the mutational spectrum and the mutagenic specificity of anthracyclines as a first step to better understand the antitumor and possible precarcinogenic effects of these compounds.

Efforts in this laboratory have focused primarily in defining the mutagenic specificity of anthracyclines using prokaryotic genotoxicity assays. The use of bacterial mutation assays is now firmly established both for fundamental studies in mutagenesis and carcinogenesis, and for screening chemicals and environmental samples for genotoxic properties. The most used and validated bacterial reverse-mutation assay is the Salmonella Mutagenicity Assay (reviewed by Mortelmans & Zeiger 2000). The original Ames tester strains (i.e., TA98, TA100, etc.) identified mutagens which reverted point mutations in the his operon of Salmonella typhimurium. Although the Salmonella Mutagenicity Assay has been widely used to screen chemicals for potential genotoxicity, it was not originally designed to yield information about the precise nature of the his\(^+\) revertants that were obtained. For example, TA100 detects primarily GC to AT events, but this strain can also detect GC to TA and extragenic tRNA suppressor mutations (Koch et al. 1994). TA98 is a tester strain that detects compounds that induce frameshift mutations (Maron & Ames 1983). A new set of Salmonella strains was subse-
quentely generated to identify specific base-substitution events (Gee et al. 1994; 1998). Since each strain can only revert by a single specific mutational event, it is not necessary to further classify or sequence the resulting revertants in order to know the mutation that has occurred.

Previous studies in this laboratory have shown that daunomycin can induce both frameshift and base-substitution transition mutations in Salmonella typhimurium (Mackay et al. 2000), while adriamycin induces frameshift and GC to AT transition events (Mackay & Phelps 2001). Interestingly, although adriamycin is structurally very similar to daunomycin, it does not induce AT to GC mutations in this assay (Mackay & Phelps 2001). The present study was initiated to examine if the "second-generation" structural analogues of daunomycin and adriamycin, namely idarubicin and epirubicin, could induce frameshift and transition mutations. This report demonstrates that both compounds can induce frameshift, GC to AT, and AT to GC transition events in Salmonella typhimurium.

**Materials and Methods**

**Bacterial strains.**—The strains and their genotypes used in this study are listed in Table 1. TA98 detects frameshift mutations (Maron & Ames 1983). TA7001 and TA7004 are base-substitution specific strains, which carry a target missense mutation in the hisG gene. The latter two strains revert to a prototrophic his+ phenotype via a specific base-substitution event (TA7001, AT to GC, and TA7004, GC to AT) (Gee et al. 1994; 1998).

**Chemicals.**—Adriamycin (doxorubicin hydrochloride), dimethyl sulfoxide (DMSO), ICR 191 acridine mutagen (6-chloro-9-[3-(2-chloroethylamino)propylamino]-2-methoxyacridine), N4-aminocytidine (N4AC), 4-nitroquinoline-N-oxide (4NQO) and streptonigrin (STN) were obtained from Sigma Chemical Co. (St. Louis). Idarubicin (Idamycin®) and epirubicin (Ellence™) were obtained from the Erie Cancer Research Center.

**Mutation assays.**—The his reversion assays (triplicate assays were conducted for each strain) followed a modified version of the traditional Ames “plate-incorporation” test (Maron & Ames 1983) which utilized
Table 1. Ames *Salmonella* strains.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Genotype</th>
<th>Mutation Detected</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA7001</td>
<td>hisG1775 Δara9 Δchl1004 (bio chlD uvrB chlA) galE503 rfa1041/pKM101</td>
<td>A:T to G:C</td>
</tr>
<tr>
<td>TA7004</td>
<td>hisG9133 Δara9 Δchl1004 (bio chlD uvrB chlA) galE503 rfa1044/pKM101</td>
<td>G:C to A:T</td>
</tr>
<tr>
<td>TA98</td>
<td>hisD3052 Δara9 Δchl1008 (bio chlD uvrB gal) rfa1004/pKM101 (-1 C)</td>
<td>frameshift</td>
</tr>
</tbody>
</table>

a pre-incubation step in order to increase the sensitivity of the strains to each anthracycline compound and has been previously described (Mackay et al. 2000; Mackay & Phelps 2001). Very briefly, 110 μL (approximately 2.0 x 10⁸ cells) of a stationary phase *S. typhimurium* culture (TA98, TA7001, TA7004) was exposed to either daunomycin, idarubicin, adriamycin, or epirubicin (120 μg/mL) for 30 minutes in a shaking incubator (250 rpm) at 37°C. 100 μL of this culture was plated onto minimal agar plates that contained 2% glucose, 0.05 mM L-histidine, and 0.005 mM biotin. These selective plates were incubated at 37°C, and the numbers of *his*⁺ revertants were scored after 48 hr. For each strain, a "zero" control (culture that was not exposed to the experimental chemical) was included in order to estimate the number of spontaneous *his*⁺ revertants in each experiment. The total number of viable cells in each experiment was determined by plating serial dilutions onto nonselective plates (Luria-Bertani, DIFCO). Mutation frequency is expressed as the average number of *his*⁺ revertants on selective plates divided by the total number of viable cells (determined by the number of colonies on the non-selective plates).

**Positive control chemicals.**—The *Salmonella* strains TA98, TA7001, and TA7004 were tested using positive control chemicals that are known to be mutagenic in this assay (Maron & Ames 1983; Gee et al. 1998; Christopher Sommers pers. comm.). ICR 191 was prepared in DMSO (4.0 μg/plate) and used as a positive control for TA98. STN, dissolved in DMSO (50 μg/plate), and N4AC, prepared in sterile deionized water (10 μg/plate) were used as positive controls for TA7001. 4NQO, dissolved in DMSO (0.4 μg/plate), and N4AC (10 μg/plate) were used as positive controls for TA7004.
RESULTS AND DISCUSSION

Previous studies in this laboratory have shown that daunomycin and adriamycin can induce frameshift (i.e., TA98) and GC to AT base-substitution mutations (i.e., TA7004) in the bacterium Salmonella typhimurium (Mackay et al. 2000; Mackay & Phelps 2001). Daunomycin also can induce AT to GC events (i.e., TA7001) in this assay (Mackay et al. 2000). However, adriamycin, a compound that is structurally very similar to daunomycin, did not induce AT to GC mutations in Salmonella (Mackay & Phelps 2001). This current study demonstrates that idarubicin and epirubicin, "second-generation" structural analogues of daunomycin and adriamycin, respectively, can induce frameshift and specific base-substitution transition events.

The Ames tester strains are listed in Table 1. Each Salmonella strain (i.e., TA98, TA7001, TA7004) was first verified using selected positive control chemicals, which have been shown to be mutagenic by Gee et al. (1994; 1998; Sommers, pers. comm.).

Strains TA98, TA7001 and TA7004 were exposed to daunomycin, idarubicin, adriamycin, or epirubicin (120 μg/ml). The number of his+ revertants were monitored on selective minimal glucose plates and total number of cells on nonselective plates. Following the calculation of the total number of viable cells, it was possible to calculate a mutation frequency for each strain tested (in triplicate). Mutation frequency is expressed as the average number of his+ revertants on selective plates divided by the total number of viable cells. The results of this study are summarized in Tables 2 and 3. TA98 was highly mutable (mutation induction folds ranged from 15.4 to 44.5; χ²: p<0.005) when exposed to daunomycin, idarubicin, adriamycin, or epirubicin in this assay. These results demonstrate that the "second-generation" structural analogues, idarubicin and epirubicin, also induced frameshift mutations in this assay. The two base-substitution Ames strains (TA7001, AT to GC; TA7004, GC to AT) were mutable in the presence of daunomycin (mutation induction folds ranged from 7.3 to 7.6; χ²: p<0.005), while TA7004 was mutable in the presence of adriamycin (mutation induction fold 7.8; χ²: p<0.005). As expected from previous studies, adriamycin did not induce AT to GC (TA7001) mutations (mutation induction fold 1.1; χ²: p>0.10) in this assay. Mutation frequencies were also deter-
Table 2. Daunomycin/Idarubicin mutation frequencies of Ames Salmonella stains.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Spontaneous Mutation Frequency (S)</th>
<th>Induced Mutation Frequency (I) (120 μg/ml daunomycin)</th>
<th>Induction Fold (daunomycin) (I/S)</th>
<th>Induced Mutation Frequency (I) (120 μg/ml idarubicin)</th>
<th>Induced Fold (idarubicin) (I/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA7001</td>
<td>0.9 (± 0.1) X 10^8</td>
<td>6.6 (± 0.1) X 10^8</td>
<td>7.3</td>
<td>2.6 (± 0.1) X 10^4</td>
<td>2.8</td>
</tr>
<tr>
<td>TA7004</td>
<td>0.8 (± 0.1) X 10^7</td>
<td>6.1 (± 0.6) X 10^7</td>
<td>7.6</td>
<td>7.0 (± 0.1) X 10^7</td>
<td>8.7</td>
</tr>
<tr>
<td>TA98</td>
<td>1.1 (± 0.3) X 10^7</td>
<td>4.9 (± 0.5) X 10^6</td>
<td>44.6</td>
<td>1.8 (± 0.3) X 10^6</td>
<td>16.1</td>
</tr>
</tbody>
</table>

mined for TA7001 and TA7004 in the presence of the "second-generation" anthracycline structural analogues, idarubicin and epirubicin. Both strains were mutable in the presence of either compound (mutation induction folds ranged from 2.8 to 14.6; χ²: p < 0.01). Thus, while adriamycin does not induce AT to GC mutations in Salmonella, the 4’-epimer of this compound, epirubicin, is mutagenic for this transition event.

Several biochemical analyses suggest that the interaction(s) between anthracyclines, primarily daunomycin and adriamycin, and DNA are complex in nature (Davies et al. 2000; Eaton et al. 2000; Qu et al. 2001). Anthracyclines can form DNA crosslinks in vivo (Skladanowski & Konopa 1994) and with GC base pairs, specifically a (GC)_4 oligonucleotide, in vitro with formaldehyde (Taatjes et al. 1997; Fenick et al. 1997). The primary mode of action (antitumor effect) of anthracyclines appears to be the intercalation of the aglycone portion of the compound between adjacent DNA base pairs, and this activity results in topoisomerase-induced DNA strand breaks (Liu 1989; Baguley & Ferguson 1998; Zunino et al. 2001). Alkylation of DNA and the production of reactive oxygen species have also been reported to cause DNA modifications during anthracycline chemotherapeutic treatments (Bokemeyer & Schmoll 1995; Olinski et al. 1997). This DNA damage has been found to possess premutagenic properties and, if not repaired, may contribute to carcinogenesis (Bokemeyer & Schmoll 1995; Olinski et al. 1998).

The amino sugar is recognized to be a critical determinant of the antitumor activity of daunomycin and adriamycin. In an attempt to improve the pharmacological properties of these anticancer drugs, novel anthracyclines have been designed with altered amino sugars. Epirubicin differs from adriamycin by the epimerization of the OH group in position 4’ of the aminosugar moiety and has been shown to be less toxic during chemotherapeutic treatments against metastatic breast
Table 3. Adriamycin/Epirubicin mutation frequencies of Ames *Salmonella* stains.

<table>
<thead>
<tr>
<th>Strain</th>
<th>Spontaneous Mutation Frequency (S)</th>
<th>Induced Mutation Frequency (I) (120 µg/ml adriamycin)</th>
<th>Induction Fold (adriamycin) (I/S)</th>
<th>Induced Mutation Frequency (I) (120 µg/ml epirubicin)</th>
<th>Induction Fold (epirubicin) (I/S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TA7001</td>
<td>0.9 (± 0.1) X 10^5</td>
<td>1.0 (± 0.1) X 10^4</td>
<td>1.1</td>
<td>2.6 (± 0.1) X 10^4</td>
<td>2.9</td>
</tr>
<tr>
<td>TA7004</td>
<td>0.8 (± 0.1) X 10^7</td>
<td>6.2 (± 0.7) X 10^7</td>
<td>7.8</td>
<td>1.2 (± 0.1) X 10^4</td>
<td>14.6</td>
</tr>
<tr>
<td>TA98</td>
<td>1.1 (± 0.3) X 10^7</td>
<td>1.7 (± 0.4) X 10^6</td>
<td>15.4</td>
<td>2.2 (± 0.3) X 10^6</td>
<td>19.7</td>
</tr>
</tbody>
</table>

Idarubicin, a 4-demethoxy-anthracycline analogue of daunomycin, exhibits several features, which render this drug unique among anthracyclines against acute nonlymphocytic leukemia. Its higher lipophilicity leads to faster accumulation within the nucleus, superior DNA-binding capacity, and consequently, a greater antitumor effect when compared to daunomycin (Borchmann et al. 1997). Furthermore, idarubicin can be administered orally at effective plasma concentrations and exhibits reduced cardiotoxicity when administered at therapeutic doses (Cerosimo 1992; Weiss 1992).

These mutational analyses also suggest that the interaction(s) between these anthracyclines and the DNA helix might indeed be very complex. Daunomycin and idarubicin exhibit similar mutagenic effects in *Salmonella* (Table 2). However, the slight differences in structure between adriamycin and epirubicin give rise to different mutational spectra in this assay. Both compounds can induce GC to AT transition mutations (Mackay & Phelps 2001; this report). However, unlike epirubicin, which can also induce AT to GC mutations (Table 3), adriamycin is not mutagenic with TA7001 in the *Salmonella* Mutagenicity Assay (Mackay et al. 2000). These results suggest that there may exist small chemical differences between the binding of each antibiotic with DNA and also suggest that unique interactions of epirubicin and adriamycin with DNA might provide an explanation for the significantly different clinical activities of the two anticancer drugs.

The incidence of many secondary cancers has been linked to high doses of chemotherapy (Kaldor et al. 1987; Swendlow et al. 1992; Olinski et al. 1997, 1998; Allen et al. 1998; Baguley & Ferguson 1998; Vakeva et al. 2000). In order to improve the clinical efficacy of anti-
neoplastic anthracycline compounds (i.e., daunomycin, adriamycin, epirubicin and idarubicin) during chemotherapy, it will be necessary to identify modulators of their activities that could potentially be exploited to sensitize target tissues to therapy or to protect nontarget tissues during therapy. Such modulators include metabolic activation pathways and DNA repair pathways.

Anthracyclines can induce DNA crosslinks (Cullinane & van Rosmalen 1994; Cullinane et al. 2000). All cells have base excision repair mechanisms, which can recognize and remove cross-linking base adducts. For example, 3-methyladenine DNA glycosylase (Aag) recognizes and removes a variety of these DNA adducts (e.g., groups that can attach at the N7 and N3 positions of the purine ring) (reviewed by Seeberg et al. 2000). *Escherichia coli* mutants (alkA tag), which lack Aag activity, are extremely sensitive to killing in the presence of monofunctional (for example, methylmethanesulfonate) and complex (for example, BCNU) alkylating agents (Evensen & Seeberg 1982; Clarke et al. 1984; Engelward et al. 1996). Furthermore, addition of a mouse gene, which encodes Aag, to alkA tag cells, restores partial resistance to cell killing in the presence of several alkylating and DNA cross-linking agents (Engelward et al. 1993). Future endeavors within this laboratory will determine if a base-excision repair pathway that includes Aag can recognize and repair anthracycline-induced DNA cross-links. Hopefully, these results may lead to a lessening of the detrimental effects of anthracycline compounds and/or increased antitumor efficacies of these drugs in future cancer chemotherapeutic treatments. These experiments are currently in progress.

ACKNOWLEDGMENTS

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LITERATURE CITED


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THE EFFECTS OF INCUBATION TEMPERATURE ON LOCOMOTOR ACTIVITY IN JUVENILE HOGNA CAROLINENSIS (ARANEAE: LYCOSIDAE)

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Abstract.—The effects of incubation temperature on locomotor activity in juveniles (third instar) of the wolf spider, Hogna carolinensis (Hentz) is reported. Egg sacs were incubated under low (24 - 26°C), medium (29 - 31°C), and high (34 - 36°C) temperatures in an environmental chamber. Locomotor activities (distance, speed and frequency) were measured for 1 h at 30°C using digital activity recording equipment. The total distance travelled, frequency of activity, and minimum and maximum speeds were significantly different when compared to incubation temperature. In general, those spiders that hatched from egg sacs incubated at 29 - 31°C travelled further and faster, and moved more frequently when compared to those incubated at lower or higher temperatures. This is the first reported effect of egg incubation temperature on locomotor activity of juvenile spiders.

Although it is well known that ambient temperature affects many morphological, physiological and developmental processes in spiders (Pulz 1987; Punzo 1991; 2000), there is little information on the effects of incubation temperature on the behavior of juveniles or adults (Punzo & Henderson 1999). Previous research has shown that the thermal and hydric environment surrounding the developing embryos of ectotherms may have a profound influence on various phenotypic traits later in life (May 1985; Scheiner 1993).

The wolf spider, Hogna carolinensis (Hentz) is the largest North American lycosid, and is widely distributed throughout the United States, southern Canada and northern Mexico (Dondale & Redner 1990). It is an ambush predator that is primarily nocturnal but may be seen occasionally during the day wandering over the surface or hiding beneath rocks (Gertsch 1979). Adult females can range in size (body length) from 22 - 35 mm, and males from 18 - 20 mm. In open, xeric habitats with sparse plant cover, these spiders frequently construct a burrow up to 30 cm in depth, with the entrance either unmodified or provided with a turret comprised of grasses, sticks or small stones depending on the location (Gertsch 1979).

In the Chihuahuan and Sonoran deserts of the southwestern United States, adult females of H. carolinensis can be found carrying their egg
sacs (attached to the posterior region of the abdomen) from early June through mid-September (Shook 1978; Punzo 2000). After emergence, the spiderlings climb onto the back of their mother and remain there for 4 - 6 days before dropping to the ground and dispersing.

This study investigated the effect of incubation temperature on locomotor activity in juveniles of *H. carolinensis*. To the author’s knowledge, this represents the first study to assess the effect of this parameter on the subsequent behavior of spiders.

**MATERIALS AND METHODS**

*General protocols and subjects.*—During June and July, 1997, 54 adult females of *Hogna carolinensis* were collected from Madera Canyon in Big Bend Ranch State Park (Brewster County, Texas), which is located in the northern region of the Chihuahuan Desert. A detailed description of this site can be found in Punzo & Henderson (1999).

Spiders were transported back to the laboratory and housed individually in plastic shoe boxes provided with a 1:1 v/v mixture of sand/peat moss substrate. They were maintained at 30° ± 0.5°C, 65-70% relative humidity, and a 12:12 h light:dark cycle in a Percival Model 85 environmental chamber (Boone, Iowa). Spiders were provided with water *ad libitum* and fed three times per week on a mixed diet of mealworms (*Tenebrio molitor*), cockroaches (*Periplaneta americana*) and crickets (*Acheta domestica*). One adult of each prey species was fed on each of the three feeding days.

Nine of the 54 females collected in the field produced fertilized egg sacs. These nine females with their egg sacs were randomly assigned to one of three incubation temperature groups: low (24 - 26°C), medium (29 - 31°C), and high (34 - 35°C). These temperature intervals were chosen on the basis of previous studies (Moeur & Eriksen 1972; Punzo & Jellies 1983) on the critical thermal minima and maxima and preferred temperatures of *H. carolinensis*, as well as on the observations that have been made over several years of captive breeding. Since previous work has shown that, depending on the species, there may or may not be any differences in the effects of diel cycling vs. constant incubation temperatures on various phenotypic traits in terrestrial arthropods (May 1985), and also on the basis of laboratory observations of *H. carolinensis*, constant temperatures were chosen for this study.
Upon hatching, the first-instar nymphs (using the classification of Vachon 1957) climbed onto the back of their mother. Juveniles were collected immediately after leaving their maternal parent (4-5 days), housed separately in 120 mL plastic containers with 1.5 cm of moist peat moss substrate, and maintained at the same temperature, humidity and photoperiod regime as the adult females. The third-instar juveniles used in these experiments were between 9-10 days old ($X \pm SE$ carapace width = 3.2 ± 0.4 mm), and were fed a mixed diet of apterous fruit flies (Drosophila melanogaster) and small cricket nymphs. All spiders were deprived of food for 24 h prior to testing.

**Measurement of locomotor performance.**—Ten juveniles that had hatched from each of the nine egg sacs were randomly chosen for each incubation temperature treatment ($N = 30$ for low, medium and high treatment groups) and tested them for locomotor performance at 30°C. Based on our observations on the diel periodicity of *H. carolinensis* in the field, all locomotor activity experiments were conducted between 2100 and 0000 hours CST. These experiments took place in an environmental chamber at 20 and 30°C and 70% relative humidity. The chamber was illuminated with an infrared lamp since most spiders are not sensitive to light at this wavelength (Foelix 1996) and should behave as they would under conditions of darkness.

Individual spiders were placed in a plastic arena (12 by 12 by 5 cm) with white strips of Whatman filter paper (Carolina Biological Supply, Burlington, NC) covering the floor. Three arenas were used simultaneously, one from each incubation temperature treatment. The position of the treatment groups (right, middle, left) was alternated between trials to control for possible effects due to position bias (Walker et al. 1999). Each spider was given 30 min to acclimate to the arena prior to testing. The filter paper was changed and the arenas washed with a dampened soapy sponge between trials to eliminate any intraspecific odor cues.

Locomotor activity was monitored for 1 h in each trial. Measurements were recorded for distance travelled (cm) and speed (cm/s) with a Sony infrared camera and an automated video digital-data collection system (Videomex-V, Columbus Instruments, Columbus, Ohio). This system converts video images to a background field of black and white pixels allowing one to continuously track a moving object (Boiteau 1997). The Videomax was set to track spiders in body length-increments and to monitor distance travelled and speed at 2-min intervals for
Figure 1. Effect of incubation temperature on the mean ± SE distance travelled by juveniles of *Hogna carolinensis* over a one hour observation period at a test temperature of 30°C. Incubation temperatures: low (24 - 26°C), medium (29 - 31°C), and high (34 - 35°C).

1 h. This is an extremely sensitive system capable of quantifying slight changes in the position of small animals (Boiteau 1997).

The total distance travelled for each spider over the 1-h period was determined by summing the distances travelled for all 2-min intervals (*N* = 30). Data from all sampling periods were used to calculate average speed. Average speed was recorded from data on the mean of all speed measurements for all 2-min intervals during which spiders exhibited movement. The fastest speed exhibited for any of the 30 two-min intervals during each 1-h observation period was considered the maximum speed.

**Statistical analysis.**—All statistical procedures followed those described by Sokal & Rohlf (1995). Because multiple measurements were taken on individual spiders over time, it was possible to use repeated measures ANOVA (between group factor is treatment temperature, and within group factor is time). Bartlett’s test for homoscedasticity showed that all behavioral data exhibited equality of variances (normality). Unplanned comparisons of differences between means were analyzed using Tukey’s least significant difference procedure (a = 0.05).
RESULTS AND DISCUSSION

The total distance travelled \((f = 5.24, P < 0.0311; \text{Fig. 1})\), frequency of bouts of activity \((f^2 = 4.89, P < 0.0284; \text{Fig. 2})\) and minimum \((f = 11.6, P < 0.01; \text{Fig. 3})\) and maximum \((f = 13.3, P < 0.01; \text{Fig. 3})\) speed of locomotion, were significantly influenced by incubation temperature. In general, those juvenile spiders that hatched from egg sacs incubated at 29 - 31° travelled further and faster, and moved more frequently when compared to those incubated at 24 - 26° and 34 - 36°. For each behavior, all pairwise comparisons between the medium incubation temperature vs. low and high temperature regimes were significant \((P < 0.05)\).

These data suggest, for the first time, that incubation temperature can exert a significant influence on locomotor activity of juvenile spiders. In this sense, the selection of an oviposition site, which can determine the thermal and hydric conditions to which the developing embryos are exposed, appears to be as important to the fitness of spiders as it is to reptiles. Unlike reptiles, female wolf spiders carry their eggs sacs and can therefore move them from less favorable to more favorable thermal
conditions. Since incubation temperature can significantly affect subsequent postembryonic behavior, it may have acted as a strong selective agent in the evolution of thermoregulatory behavior in lycosids.

After leaving their mothers, juvenile wolf spiders must disperse and find suitable prey and shelter. Owing to their small size, they are particularly vulnerable to predation and desiccation at this stage (Punzo & Jellies 1983; Pulz 1987; Punzo 2000). Spiders that move more frequently, and travel further and faster, should have an advantage in these respects. Enhanced locomotor activity may increase their consumption of prey resulting in faster growth rates and larger body size. As a result, attaining sexual maturity more rapidly may result in the production of multiple egg sacs or the insemination of more females (Morse 1994), and larger body size is often associated with increased fecundity (Marshall & Gittleman 1994; Punzo & Henderson 1999). In addition, faster maximum running speeds should enhance their ability to escape from cursorial predators.

Future studies on spiders should investigate the effects of incubation temperature on reproductive success and morphological traits of off-
spring, as well as on additional behaviors including emergence, dispersal, escape behavior, agonistic interactions, the ability to detect and capture prey, courtship, thermoregulation and burrow or web construction.

ACKNOWLEDGMENTS

We are grateful to R. Shaw, L. Costa, C. Bradford and anonymous reviewers for helpful comments on an earlier draft of the manuscript, B. Garman for consultation on statistical procedures, H. Cummings for use of his Videomex-V digital data analysis system, and T. Punzo for assistance in maintaining animals in captivity. This research adhered to the Guidelines for the Use of Animals in Research of the Animal Behavior Society as well as approved protocols outlined by the University of Tampa (UT). A Faculty Development Grant to F. Punzo from UT provided financial support for much of this work.

LITERATURE CITED


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DISTRIBUTIONAL RECORDS OF MAMMALS FROM THE PERMIAN BASIN, TEXAS

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Abstract.—County records for mammals in the Permian Basin are reported based on fieldwork and museum surveys. Twenty-six records representing 20 species are reported from Crane, Ector, Loving, Ward and Winkler counties.

The Permian Basin is composed of five Texas counties (Crane, Ector, Loving, Ward and Winkler) located east of the Pecos River. This area is an ecotonal zone at the junction of three major ecogeographic regions of Texas: the Edwards Plateau, the Llano Estacado and the Trans-Pecos (Blair 1950). The region is a roughly wedge shaped basin framed by the higher elevations of the Edwards Plateau and the Llano Estacado and slopes to the Pecos River.

Although currently recognized as part of the Big Bend geographic region by the Texas Parks and Wildlife Department (Holt et al. 2000), the Permian Basin was not included in the extensive surveys of Trans-Pecos mammals (Schmidly 1977). Goetze (1998) reported on mammals from parts of Crane and Ector counties as part of his work on the mammals of the Edwards Plateau. Information on mammals from portions of Winkler and Ector counties was included in the surveys of the Llano Estacado (Choate 1997). The majority of the Permian Basin, however, has been overlooked in ecogeographic surveys of mammals.

Davis & Schmidly (1994) predicted that the Permian Basin should have approximately 55-60 mammal species. Currently only 41 species have been reported from this area. Brant & Lee (1999) speculated that the reason for the paucity of information on the mammalian fauna is due to the remoteness of the area. In addition, most of the species currently reported for this area are the result of single night collecting efforts while traveling to a more distant location instead of a systematic survey of the region. Recent fieldwork conducted in the Permian Basin and surveys of specimens in museums have resulted in 26 county records.
unreported previously for the region.

METHODS

Fieldwork was conducted from October 2000 to August 2001 in Monahans Sandhills State Park and the surrounding areas of Ward and Winkler counties in conjunction with a mammal survey of the state park. Standard techniques were utilized to collect small and medium-sized mammals (Jones et al. 1996). Voucher specimens were prepared as standard museum study skins with skulls and frozen tissue. All materials were deposited in the Collection of Recent Mammals in the Natural Science Research Laboratory of the Museum of Texas Tech University.

In addition, a survey of systematic collections was conducted for records of mammals from the Permian Basin. Specimen records were obtained from the following systematic collections: Collection of Recent Mammals, Midwestern State University (MWSU), Strecker Museum, Baylor University (SM), Vertebrate Collection, Sul Ross State University (SRSU), Museum of Texas Tech University (TTU), National Museum of Natural History (USNM) and Centennial Museum, University of Texas at El Paso (UTEP).

SPECIES ACCOUNTS

The following accounts treat 20 species representing 26 county records for the Permian Basin. The arrangement of taxa and taxonomic nomenclature follows that of Manning & Jones (1998).

*Didelphis virginiana* (Virginia opossum).—One female specimen (SRSU 1292) of this relatively uncommon species was collected in December 1968 from the Texas-New Mexico Tank Farm Bridge in Crane County. This represents the second record of this species from the Permian Basin with the only other voucher from Ward County (Davis & Schmidly 1994).

*Sylvilagus audubonii* (desert cottontail).—A male desert cottontail (TTU 69433) was collected on 25 March 1995 from 12 miles north and five miles west of the city of Crane in Crane County. This species is not unexpected for the Permian Basin with records in every other county
(Davis & Schmidly 1994; Brant & Lee 1999).

*Ammospermophilus interpres* (Texas antelope ground squirrel).—G. Donald of the U. S. Biological Survey collected a male specimen (USNM 118732) on 13 September 1902 from the Grand Falls region of the Castle Mountains in southern Ward County. This species is characteristic of xeric regions and reaches its northeastern distributional limit on the Permian Basin and Edwards Plateau with records from Crane and Reagan counties (Davis & Schmidly 1994).

*Spermophilus spilosoma* (spotted ground squirrel).—A female specimen (SM 850) was collected on 8 April 1966 from 12 miles north of Mentone in Loving County. The locality of this specimen is well within the distributional range of the species with records from three counties in the Permian Basin (Davis & Schmidly 1994).

*Spermophilus variegatus* (rock squirrel).—M. Cary of the U. S. Biological Survey collected a female rock squirrel (USNM 118601) on 12 September 1902 from the Castle Mountains of southern Ward County. This specimen represents the first record of *S. variegatus* in the Permian Basin.

*Cynomys ludovicianus* (black-tailed prairie dog).—A single female specimen (UTEP 3545) was collected on 24 June 1972 from 3.75 miles north and 1.5 miles east of the county building in Crane County. The record of this specimen is well within the distributional limit of the species and records are known from two other Permian Basin counties (Davis & Schmidly 1994).

*Thomomys bottae* (Botta’s pocket gopher).—M. Cary of the U. S. Biological Survey collected a female specimen (USNM 118582) on 12 September 1902 from the Castle Mountains in southern Ward County. This species is only known from the Trans-Pecos, Edwards Plateau and the southern portion of the Permian Basin (Davis & Schmidly 1994).

*Chaetodipus intermedius* (rock pocket mouse).—On 27 July 1987, a male *C. intermedius* (TTU 47218) was collected from four miles south and two miles east of the city of Crane in Crane County. Five specimens of the rock pocket mouse (TTU 47221-47225) were collected from Ward County on 25 July 1987 from two miles west of Barstow. These
six records from Crane and Ward counties are at the eastern limit of the geographical distribution of this species, which only occurs east of the Pecos River in the Permian Basin (Davis & Schmidly 1994).

*Reithrodontomys megalotis* (western harvest mouse).—A male western harvest mouse (TTU 45589) was collected on 19 April 1987 from two miles north and five miles east of Mentone in Loving County. Two additional specimens (TTU 45590-45591) were collected on 20 April 1987 from two miles west of Mentone. Two specimens of *R. megalotis* have been collected from Ward County. On 13 March 1969, a male (UTEP 4680) was collected from along the Pecos River near US Highway 80. Another specimen (TTU 82484) was collected from the Pump Jack Picnic Area (13R 706632E, 3502752N) of Monahans Sandhills State Park on 18 October 2000. These five records for Loving and Ward counties provide further insight into the range of this relatively uncommon species, which reaches its eastern distributional limits on the Edwards Plateau and the Llano Estacado (Davis & Schmidly 1994).

*Reithrodontomys montanus* (plains harvest mouse).—On 8 March 1987, a female plains harvest mouse (MWSU 14511) was collected from nine miles west of Monahans in Ward County. This species is relatively rare in the Trans-Pecos (Schmidly 1977) and the Edwards Plateau (Goetze 1998). This species has been recorded from Ector and Winkler counties in the Permian Basin (Davis & Schmidly 1994).

*Peromyscus leucopus* (white-footed mouse).—Several specimens of the white-footed mouse were collected from Loving and Ward counties. Four females and seven males were collected on 19-20 March 1987 from 1 mile west of Mentone (TTU 45571); two miles north and five miles west of Mentone (TTU 45572-45576); and two miles west of Mentone (TTU 45577-45581) in Loving County. A male (TTU 47267) was collected from three miles east of Mentone on 26 August 1987. Another specimen (TTU 69517) was collected eight miles north and eight miles east of Orla on 7 August 1994. Twenty-nine specimens (16 females and 13 males) have been collected from Ward County. A male (TTU 44210) was collected on 1 March 1986 from eight miles west-southwest of Monahans. Four specimens (TTU 53983-53986) were collected from nine miles west of Monahans on 7-8 March 1987. On 25 July 1987, three specimens (TTU 47276-47278) were collected from two miles west of Barstow. Eight *P. leucopus* (TTU 69518-69525) were
collected on 5 November 1994 from Monahans Sandhills State Park. Three specimens (TTU 69526-69528) were collected from two miles north of Monahans on 16 March 1995. Ten specimens (TTU 82481-82482, 82485-82492) have been collected from Monahans Sandhills State Park from October 2000 to July 2001.

*Peromyscus maniculatus* (deer mouse).—Three deer mice (TTU 45582-45584) were collected on 19 March 1987 from one mile west of Mentone in Loving County. This relatively common species is distributed statewide with records for all of the surrounding counties (Davis & Schmidly 1994).

*Onychomys leucogaster* (northern grasshopper mouse).—Two northern grasshopper mice have been collected from Loving County. A female (TTU 45569) was collected on 19 March 1987 from two miles north and five miles east of Mentone. A male (TTU 58417) was collected on 13 July 1990 from two miles northeast of Mentone. This species is distributed throughout western Texas (Davis & Schmidly 1994) but is relatively rare in the Trans-Pecos (Schmidly 1977).

*Sigmodon hispidus* (hispid cotton rat).—Several hispid cotton rats have been collected from Loving and Ward counties. Ten *S. hispidus* were collected from Loving County in 1987 from three localities: three females (TTU 45594-45596) collected on 19 March 1987 from one mile west of Mentone; five females and one male (TTU 45597-45602) collected on 20 March 1987 from two miles west of Mentone; and a female (TTU 47325) collected on 26 August 1987 from three miles east of Mentone. Four *S. hispidus* have been collected from Ward County. On 25 July 1987, a female (TTU 47334) was collected from two miles west of Barstow. A male and a female (TTU 69537-69538) were collected from Monahans Sandhills State Park on 11 September 1994. Another male (TTU 82483) was collected from the Pump Jack Picnic Area (13R 706632E, 3502752N) of Monahans Sandhills State Park on 18 October 2000.

*Urocyon cinereoargenteus* (gray fox).—On 5 January 1969, a male gray fox (SRSU 1291) was collected from the Texas-New Mexico Tank Farm Bridge in Crane County. Another specimen (UTEP 2862) was collected from Crane County on 24 June 1972. This species is distributed throughout Texas, but has only been recorded from one other
county in the Permian Basin (Davis & Schmidly 1994).

*Procyon lotor* (raccoon).—One specimen of the raccoon (TTU 82493) was collected on 10 July 2001 from Pump Jack Picnic Area (13R 706632E, 3502752N) of Monahans Sandhills State Park in Ward County. This relatively common species has only been recorded from one other Permian Basin county (Davis & Schmidly 1994) and is usually associated with watercourses in the Trans-Pecos (Schmidly 1977).

*Mustela frenata* (long-tailed weasel).—On 24 June 1972, a single male long-tailed weasel (UTEP 3618) was collected from 3.75 miles north and 1.5 miles east of the county building in Crane County. The records for this rare species in Texas are scattered throughout most of the state (Davis & Schmidly 1994). This is the first record for *M. frenata* from the Permian Basin.

*Taxidea taxus* (American badger).—The American badger was collected from three counties in the Permian Basin. On 22 October 1987, a female (TTU 49077) was collected from 14 miles south and two miles east of Crane in Crane County. Another female (MWSU 18020) was collected on 28 March 1991 from 17.9 miles west-southwest of Midland in Ector County. In Ward County a female (MWSU 6045) was collected on 10 May 1968 from 35 miles southwest of Monahans. This species ranges throughout most of Texas but until now has not been recorded from the Permian Basin (Davis & Schmidly 1994).

*Mephitis mephitis* (striped skunk).—M. Cary of the U. S. Biological Survey collected a male striped skunk (USNM 118618) on 12 September 1902 from the Castle Mountains in southern Ward County. This species is common throughout Texas, but has not been recorded from the Permian Basin until now (Davis & Schmidly 1994).

**Conclusions**

The 26 county records reported in this study help to fill in the gap in the understanding of Texas mammals of that geographical area known as the Permian Basin. Only four of the 20 species reported herein have never been reported from the Permian Basin; *Mephitis mephitis*, *Taxidea taxus*, *Mustela frenata* and *Spermophilus variegatus*. These four species increase the mammalian diversity of the area to 45 species, closer to the
predicted value of 55-60 (Davis & Schmidly 1994). Undoubtedly more elusive species will be encountered with further research and a systematic survey of this neglected area.

ACKNOWLEDGMENTS

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LITERATURE CITED


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GENERAL NOTES

NOTEWORTHY RECORDS OF BATS FROM THE TRANS-PECOS REGION OF TEXAS

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Recent investigations of bat communities in the Trans-Pecos region of Texas provided noteworthy records for six species (*Myotis californicus*, *Myotis volans*, *Lasiurus borealis*, *Nyctinomops femorosaccus*, *Nyctinomops macrotis* and *Eumops perotis*). All voucher specimens reported herein (skins and skulls), and their associated tissues, are deposited in the Collection of Recent Mammals in the Natural Science Research Laboratory of the Museum of Texas Tech University (TTU).

*Myotis californicus*.—The California myotis is an established resident of the Trans-Pecos area and has been documented in El Paso, Culberson, Jeff Davis, Presidio and Brewster counties, yet records of this species from Hudspeth County are lacking (Schmidly 1991; Davis & Schmidly 1994). Two females (TTU 82465, 82467) were obtained with mist nets set across a pool of a desert spring on 18 June 2001 at the Indio Mountains Research Station (University of El Paso), Hudspeth County (UTM 13R 498907E 3407109N, elevation 1280m). The edges of the pool were overgrown with cattail (*Typha* sp.) and a rock ridge bordered the northeast side. The surrounding vegetation consisted of thorny desert scrub, including acacia (*Acacia* sp.), yucca (*Yucca* sp.) and prickly pear (*Opuntia* sp.). The discovery of *M. californicus* in Hudspeth County completes a contiguous distribution of this species across the western Trans-Pecos region. Associated species of bats encountered at this site on 18 June include *Pipistrellus hesperus*, *Antrozous pallidus*, *Myotis velifer* and *Myotis volans*.

*Myotis volans*.—The long-legged myotis is considered relatively rare in Texas, yet it is common in the higher elevations of extreme western Texas. In the Trans-Pecos area, this species has been documented in the mountainous regions of Culberson, Jeff Davis, Presidio and Brewster counties, with an addition record from Knox County in the Rolling
Plains (Schmidly 1991; Davis & Schmidly 1994). On 18 June 2001, one female *M. volans* (TTU 82466) was captured at the Indio Mountains Research Station (locality same as above). The elevation of the capture site (1280m) is atypical of that associated with *M. volans* in west Texas, as it is usually found between 2000 to 3000m (Warner & Czaplewski 1984). Other bats captured in association with this species on 18 June were *M. velifer*, *M. californicus*, *P. hesperus* and *A. pallidus*.

*Lasiurus borealis*.—The eastern red bat displays a spotty distribution in the Trans-Pecos region, where it typically is found in mountainous terrain (Schmidly 1991; Davis & Schmidly 1994). Three pregnant females (TTU 82478, 82479, 82480), each having three embryos with crown rump lengths ranging from 12 to 20mm, were captured in mist nets on 22 May 2001 at Big Bend Ranch State Park (BBRSP), Presidio County (UTM 13R 589266E 3269761N, elevation 1012m). In Presidio County, *L. borealis* is known from the Chinati Mountains (Schmidly 1991) and the Sierra Vieja (Jones & Bradley 1999). Yancey’s (1997) comprehensive survey of the mammals of BBRSP produced no record of *L. borealis*, yet he listed it as a probable summer migrant of the surrounding riparian woodland habitats.

The capture site was characterized by a dense growth of cottonwoods (*Populus* sp.) comprising a riparian gallery forest spanning more than three kilometers in length. The site was spring-fed and water levels along this intermittent stream varied little between visits throughout the spring and summer in 2001. This locality is atypical of Chihuahuan Desert habitat, and it likely plays an important role in providing suitable roosting and foraging grounds for bats. The embryos obtained were approaching full-term developmentally, suggesting the adults were to give birth in the area. Forty-one bats were captured with *L. borealis* on 22 May, including *Mormoops megalophylla*, *M. californicus*, *P. hesperus*, *Lasiurus cinereus*, *A. pallidus* and *Tadarida brasiliensis*.

* Nyctinomops femorosaccus. — The distribution of the pocketed free-tailed bat in Texas is quite restricted, and previously has been documented only from Big Bend National Park (BBNP), Brewster County (Easterla 1968; Schmidly 1991; Higginbotham & Ammerman 2002). One lactating female (TTU 82477) was collected in a mist net over a stock tank on 6 July 2001 at BBRSP, Presidio County (UTM 13R 602303E 3258748N, elevation 1300m) in desert scrub habitat dominated by creosote bush (*Larrea tridentata*). This record expands the known
distribution of this species in Texas 80km west of the previously known range and represents the first account for this species from Presidio County. Yancey (1997) reported *N. femorosaccus* as a likely occurrence in BBRSP, yet he did not encounter any during his extensive survey of the mammals there. During a recent study in nearby Brewster County at BBNP, *N. femorosaccus* was encountered only in nets stretched over open water with sizeable surface area (Higginbotham & Ammerman 2002). The ephemeral nature of full stock tanks and other sizeable bodies of water at BBRSP may explain the species’ absence from past studies in the area. The pocketed free-tailed bat roosts in crevices of high rocky canyons in BBNP (Higginbotham & Ammerman 2002). Deep canyons with suitable crevices are numerous at BBRSP, and it is likely that roosts of *N. femorosaccus* occur within them. *Eptesicus fuscus*, *T. brasiliensis*, *Nyctinomops macrotis* and *Eutnops perotis* were captured on 6 July in association with this species.

*Nyctinomops macrotis*.—Reports of the big free-tailed bat from the Trans-Pecos area are scattered sparsely across both upland and lowland habitats in Brewster, Presidio, Jeff Davis, Reeves, Culberson and El Paso counties (Schmidly 1991; Davis & Schmidly 1994). An adult female (TTU 82469) was captured on 1 July 2001 at an upland site within coniferous forest at the Davis Mountains Preserve (The Nature Conservancy of Texas), Jeff Davis County (UTM 13R 584126E 3394303N, elevation 1860m). The rare occurrence of this species in the Davis Mountains uplands is evidenced by systematic studies of mammals in the vicinity since 1998, in which only a single specimen of *N. macrotis* has been encountered at the Davis Mountains Preserve (Bradley et al. 1999).

Additionally, one pregnant female *N. macrotis* (TTU 82468; embryo crown-rump length = 27.5mm) was collected on 29 May 2001 at the same locality in BBRSP as the previously reported *L. borealis*. Eight lactating females (TTU 82469, 82470, 82471, 82472, 82473, 82474, 82475) were taken on 6 July 2001 in mist nets at BBRSP at the same site as the *N. femorosaccus* discussed above. These two localities represent vastly different habitats within BBRSP. The former was a riparian gallery forest bordering a narrow, intermittent stream, and the latter, a stock tank (surface area 15 by 20m) within desert scrub habitat. A single specimen of *N. macrotis* was obtained at BBRSP prior to the work reported herein (Yancey 1997).

In Texas, encounters of significant numbers of *N. macrotis*
historically have been documented only from BBNP in Brewster County (Borell & Bryant 1942; Easterla 1973; Higginbotham & Ammerman 2002). However, recent investigations of mammals at the Davis Mountains State Park, Jeff Davis County, have produced several captures of *N. macrotis* at a lowland site. These accounts suggest that *N. macrotis* is perhaps more common in the Trans-Pecos region than was thought previously.

*Eumops perotis.*—Reports of the western mastiff bat from Texas are few, and all originate from the Trans-Pecos region in proximity to the Rio Grande corridor (Schmidly 1991). This work reports an additional record of one adult male (TTU 82476) collected at BBRSP on 6 July 2001 from the same locality as the aforementioned molossids (*N. femorosaccus* and *N. macrotis*). Three reports exist for *E. perotis* from Presidio County over the past 45 years (Eads et al. 1957; Ohlendorf 1972; Scudday 1976). Scudday (1976) mentions *E. perotis* as fairly common at Arroyo Segundo (BBRSP), a site also netted by Yancey (1997). This same locality was surveyed several times during summer 2001, yet no western mastiff bats were encountered.

Maneuvering ability is apparently compromised in the western mastiff bat due to its wing morphology and large size (Findley et al. 1971), and therefore it probably avoids smaller bodies of water, or enclosed areas. *Eumops perotis* is known to roosts in crevices within high canyon walls typical of the rocky, rugged terrain of the Big Bend region, therefore, they may be more common in the area than the historical capture data suggests, yet more difficult to capture where large bodies of water are scarce.

*Eumops perotis, N. femorosaccus* and *N. macrotis* were encountered together at a single locality although extensive sampling was conducted throughout BBRSP during this survey and by Yancey (1997). A distinguishing feature of the site where all three species were captured was the size of the tank (15 by 20 m). When nets spanned the center of the tank, 93% of mist net captures consisted of the four species of molossids known to inhabit the area, including *Tadarida brasiliensis*. During sampling periods when mist nets were set only along the perimeter of the tank, molossids were not encountered in the nets, although audible echolocation calls associated with both *E. perotis* and *N. macrotis* frequently were heard throughout the evening. This suggests that the larger molossid species inhabiting the Trans-Pecos region of Texas are
obligates of large, open water sources for drinking. Therefore, the rarity with which these bats are encountered in the Trans-Pecos area may be explained in part by the significant fluctuation in surface area of sizeable, reliable water sources in the region. Consequently, the adjacent Rio Grande is an important resource for these species, as it is a stable source of water relative to other, often ephemeral, sources of water in the region.

ACKNOWLEDGMENTS

The fieldwork and collection of specimens were conducted in accordance with scientific permits issued by the Texas Parks and Wildlife Department (SPR-0790-189 and 55A-00). Financial assistance was facilitated by research assistantships granted to J. L. Higginbotham, R. S. DeBaca and J. G. Brant during the summer of 2001 by the Department of Biological Sciences at Texas Tech University. Access to the Indio Mountains Research Station was provided by J. D. Johnson, University of El Paso. Access and logistic support were provided by the Nature Conservancy of Texas and by the personnel of the Big Bend Ranch State Park (L. Armendariz, Superintendent). M. Revelez, M. A. Abbey, A. Matthews and B. Reece assisted in the collection and preparation of specimens.

LITERATURE CITED

GASTROINTESTINAL HELMINTHS OF GAIGE’S TROPICAL NIGHT LIZARD, *LEPIDOPHYMA GAIGEAE* (SAURIA: XANTUSIIDAE) FROM HIDALGO, MEXICO

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Gaige’s tropical night lizard, *Lepidophyма gaigeae* Mosauer, occurs in limestone crevices within pine-oak woodlands in the Mexican states of Hidalgo and Querétaro (Bezy 1984). To the author’s knowledge, there are no reports of helminths from this lizard.

Fifty-five *Lepidophyма gaigeae* (mean snout-vent length, SVL = 54 mm ± 4.4 SD, range = 42-63 mm; 22 females, SVL = 53 mm ± 5.1, range = 42-63 mm; 33 males, SVL = 54 mm ± 3.8, range 45-62 mm) were collected at Durango, Hidalgo (20°54’N, 99°14’W) March 1999 to February 2000. Lizards were fixed in 10% formalin, preserved in alcohol and deposited in the herpetology collection of the Escuela Nacional de Estudios Profesionales Iztacala, Universidad Nacional Autónoma de México: ENEPI 6978-6981, 6983-6985, 7003, 7062, 7116-
The abdominal cavity of each lizard was opened and the gastrointestinal tract was excised by cutting across the esophagus and rectum. Each tract was slit longitudinally and examined under a dissecting microscope for helminths. When found, helminths were removed to a drop of undiluted glycerol on a glass slide for initial study.

One species of Cestoda, Bitegmen gerrhonoti (Telford 1965) and two species of Nematoda, gravid individuals of Spauligodon giganticus (Read & Amrein 1953) and larvae of Ascaridia sp. were found. Selected specimens were placed in vials of 70% ethanol and deposited in the United States National Parasite Collection (USNPC), Beltsville, Maryland (Table 1). Because there was no statistical difference for SVL between male and female lizards in the sample (Kruskal Wallis = 1.34, 1 df, P > 0.05) and because there was no statistical difference for infection by S. giganticus and Ascaridia sp. (only 1 male lizard infected with B. gerrhonoti) between male and female lizards ($\chi^2 = 1.35$, 0.01, 1 df, $P > 0.05$, respectively), results are presented as a single data set. Prevalence, mean intensity, range and abundance as defined by Bush et al. (1997) are given in Table 1 for each helminth species.

*Bitegmen gerrhonoti*, originally described as *Baerietta gerrhonoti* by Telford (1965) from the southern alligator lizard, *Elgaria multicarinata* (= *Gerrhonotus multicarinatus webbi*), was reassigned to its current taxonomic position by Jones (1987). This is the second report of *B. gerrhonoti* in lizards; it is also known from the salamander *Ensatina eschscholtzii* from southern California (Goldberg et al. 1998). The life cycle of *B. gerrhonoti* is unknown, but Joyeux (1927) regards the life history of nematotaeniid cestoides to be direct; infection of a new host occurs through ingestion of eggs. *Lepidophyma gaigeae* is a new host record; Mexico is a new locality record.

*Spauligodon giganticus* is a common intestinal helminth of North American lizards, especially sceloporine lizards; additions to the host list provided by Bursey & Goldberg (1992) are presented in Goldberg et al. (2003). The life cycle of *S. giganticus* has not been studied; but the life cycles of other oxyurids are direct and infection is by an oral route (Anderson 2000). Goldberg & Bursey (1992) found eggs of *S. giganticus* in the digestive tracts of neonatal *Sceloporus jarrovii* indicating that
Table 1. Accession number, prevalence, mean intensity, range and abundance for helminth species from *Lepidophyma gaigeae* from Hidalgo, Mexico.

<table>
<thead>
<tr>
<th>Helminth</th>
<th>USNPC #</th>
<th>Prevalence</th>
<th>Mean intensity ± SD</th>
<th>Range</th>
<th>Abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Bitegmen gerrhonoti</em></td>
<td>91755</td>
<td>2%</td>
<td>3</td>
<td>—</td>
<td>0.05</td>
</tr>
<tr>
<td><em>Spauligodon giganticus</em></td>
<td>91756</td>
<td>76%</td>
<td>8.1 ± 5.9</td>
<td>1-26</td>
<td>6.20</td>
</tr>
<tr>
<td><em>Ascaridia</em> sp.</td>
<td>91757</td>
<td>24%</td>
<td>8.3 ± 13.6</td>
<td>1-51</td>
<td>1.96</td>
</tr>
</tbody>
</table>

Infection takes place soon after birth; young lizards presumably acquire eggs by ingesting substrate. *Lepidophyma gaigeae* is a new host record and the first xantusiid known to harbor *S. giganticus*.

Larvae of *Ascaridia* sp. were found encysted on the outer wall of the digestive tract. Moravec & Kaiser (1995) reported encystment by larvae of similar description in species of *Eleutherodactylus* collected in Dominica and Tobago, West Indies. Species of *Ascaridia* are common parasites of gallinaceous birds; eggs and larvae can be harbored by earthworms (Anderson 2000). This is the first report of *Ascaridia* sp. in a lizard species and may represent an accidental infection which could occur in any vermivore.

**LITERATURE CITED**


Joyeux, C. 1927. Recherches sur la faune helminthologique Algérienne (cestodes et

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DESCARTES’ AND HESSIAN FOLIUMS

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Abstract.—The conic polars of \( x^3 + y^3 = 3axy \) are called the Hessian Foliums. The set of areas of the loops of this set becomes a convergent infinite series. Also the set of lengths of these loops gives another convergent series (Bagchi 1939).

1. THE FOLIUM

The equation of the DesCartes’ folium is

\[
x^3 + y^3 = 3axy.
\]

For simplicity let \( a = 1 \). Then one obtains a set of parametric equations for (1) by the following set of equations

\[
\begin{align*}
x^3 + y^3 &= 3xy \\
y &= tx.
\end{align*}
\]

This set of equations will give

\[
x^3(1 + t^3) = 3x^2t.
\]

From (2) and (3) one obtains

\[
\begin{align*}
x &= \frac{3t}{1 + t^3} \\
y &= \frac{3t^2}{1 + t^3}.
\end{align*}
\]

For the points at infinity (\( \infty \)) one lets \( 1 + t^3 \) approach zero, that is,

\[
1 + t^3 = (1 + t)(1 - t + t^2) \rightarrow 0.
\]
One observes that \(1 - t + t^2 \neq 0\). So in order to obtain (5) one must let \(t\) approach \(-1\). This implies that the asymptote of the curve is parallel to \(y = -x\) or \(x + y = 0\).

Let the asymptote be

\[
y = - x + b. \tag{6}
\]

Then

\[
b = \lim_{t \to -1} (y + x) = 3 \lim_{t \to -1} \frac{t^2 + t}{1 + t^3}. \tag{7}
\]

Employing L'Hospital's rule, one gets

\[
b = 3 \lim_{t \to -1} \frac{2t + 1}{3t^2} = -1 \tag{8}
\]

So (6) and (8) imply that the asymptote is

\[
y = - x - 1. \tag{9}
\]

Now change (1) to the polar coordinates. So one gets \(r^3(\cos^3 \theta + \sin^3 \theta) = 3r^2 \sin \theta \cos \theta\), which yields

\[
r = \frac{3 \sin \theta \cos \theta}{\cos^3 \theta + \sin^3 \theta}. \tag{10}
\]

Clearly the graph is symmetrical with respect to \(y = x\). Therefore for the graph one only considers \(\frac{\pi}{4} \leq \theta \leq \frac{3\pi}{4}\) which, along with the \(y = x\) symmetry, allows one to sketch the graph. Or with the use of a computer, one can obtain a good graph (Figure 1).

Figure 1.
One may observe that (1) in polar coordinates is
\[ r = \frac{3as \sin \theta \cos \theta}{\cos^3 \theta + \sin^3 \theta}. \]  \hspace{1cm} (11)

So in general other foliums can be obtained from Figure 1 by homothetic transformations.

2. HOMOGENEOUS COORDINATES

If one lets \( x = \frac{X}{Z} \) and \( y = \frac{Y}{Z} \) in (1), one obtains
\[ \left( \frac{X}{Z} \right)^3 + \left( \frac{Y}{Z} \right)^3 - 3a \frac{XY}{Z^2} = 0. \] \hspace{1cm} (12)

One can write (12) as
\[ X^3 + Y^3 - 3aXYZ = 0. \] \hspace{1cm} (13)

Note that \( Z \to 0 \) corresponds to the points at \( \infty \). One may obtain the asymptote by letting \( Z \to 0 \) in (13). Since the asymptote has already been obtained, one shall not pursue this method.

3. THE CONIC POLAR

Let \( A(p,q) \) be a point in the plane of a plane curve of a third degree equation. Let \( f(x,y,z) = 0 \) be the homogeneous equation of the curve. (Note that small letters have been used instead of \( X, Y, Z \)). Let \( (p,q,r) \) be the set of homogeneous coordinates of \( A \). Then
\[ p \frac{\partial f}{\partial x} + q \frac{\partial f}{\partial y} + r \frac{\partial f}{\partial z} = 0 \] \hspace{1cm} (14)

is defined to be the conic polar of \( A \) with respect to \( f(x,y) = 0 \).

Now one shall apply (14) to the folium \( x^3 + y^3 - 3axyz = 0 \). So one obtains
\[ p(3x^2 - 3ayz) + q(3y^2 - 3axz) + r(-3axy) = 0. \] \hspace{1cm} (15)

By setting \( z = 1 \) and \( r = 1 \), this equation in ordinary Cartesian coordinates will be
\[ p(x^2 - ay) + q(y^2 - ax) - axy = 0. \] \hspace{1cm} (16)

Simplifying (16) one gets
\[ px^2 - axy + qy^2 - aqx - apy = 0. \] \hspace{1cm} (17)
Note that (17) is the equation of a conic section.

4. TYPES OF CONIC SECTIONS

Consider the second degree equation

\[ ax^2 + bxy + cy^2 + px + qy + d = 0. \]  (18)

Besides real and imaginary circles, there are nine cases to be considered. The following is a list:

- I. The real ellipse,
- II. The imaginary ellipse,
- III. Imaginary intersecting lines,
- IV. The hyperbola,
- V. Real intersecting lines,
- VI. The parabola,
- VII. Imaginary parallel lines,
- VIII. Real parallel lines,
- IX. Two coincidental lines.

Essentially one puts all these into three categories:

(i) Ellipse, where \( b^2 - 4ac < 0 \),
(ii) Parabola, when \( b^2 - 4ac = 0 \),
(iii) Hyperbola, when \( b^2 - 4ac > 0 \).

Degenerate cases are parts of these categories, for example, two intersecting lines is a special case of hyperbola and satisfies (iii).

For this study, one shall study the necessary and sufficient condition for which (18) is two lines. Let one write (18) as a quadratic equation in \( x \); that is,

\[ ax^2 + (by + p)x + cy^2 + qy + d = 0. \]  (19)

For (19) to become two straight lines, one must have its discriminant to be a perfect square. The discriminant of (19) is

\[ (by + p)^2 - 4a(cy^2 + qy + d). \]  (20)

This is a polynomial of degree two in \( y \). For (20) to be a perfect square, its discriminant has to be zero. One shall apply this last part of this section to (17).
5. HESSIAN FOLIUMS

One can write (17) as
\[ px^2 - a(y + q)x + qy^2 - apy = 0. \] (21)

The discriminant of (21) is
\[ \Delta = a^2 (y + q)^2 - 4pq(qy^2 - apy). \] (22)

Now write \( \Delta \) as a second degree polynomial in \( y \), that is
\[ (a^2 - 4pq)y^2 + 2(a^2q + 2ap^2)y + a^2q^2 \] (23)

So setting the discriminant of (23) equal zero, one obtains
\[ (a^2q + 2ap^2)^2 - a^2q^2(a^2 - 4pq) = 0. \] (24)

Simplifying one gets
\[ p^3 + q^3 + apq = 0. \] (25)

This is quite interesting, because it means the locus of \( A(p,q) \) whose polar with respect to the folium \( x^3 + y^3 = 3axy \) is a pair of straight lines is another folium; that is
\[ x^3 + y^3 = -axy. \] (26)

Bagchi (1939) calls this the Hessian folium of (1). Note that (26) is homothetic of (1) with center 0, the origin and ratio \(-\frac{1}{3}\).

6. THE SET OF HESSIAN FOLIUMS

If one applies to (26) what has been done for (1) one obtains another folium which is homothetic of (26) with ratio \(-\frac{1}{3}\). This way one obtains
\[ x^3 + y^3 = \frac{1}{3}axy. \] (27)

Without loss of generality one can let \( a > 0 \). Then the set of so-called Hessian foliums are obtained from (1) by homothetic transformations of center \((0,0)\) a ratio \(-\frac{1}{3}\). Call these \( \Lambda_1, \Lambda_2, \Lambda_3, \ldots \) as follows:
\begin{align*}
&\begin{cases}
\Lambda_1: & x^3+y^3 = a^2 xy, \\
\Lambda_2: & x^3+y^3 = -a^2 xy,
\end{cases} \\
&\text{...} = \text{...} \quad (28)
\end{align*}

7. AREAS OF HESSIAN FOLIUMS

First one obtains the area of the loop of (1). One gives the details. Let the area be \( A \). Then

\[
A = \frac{1}{2} \int_0^\pi r^2 d\theta, 
\]

where

\[
r = \frac{3a \sin \theta \cos \theta}{\sin^3 \theta + \cos^3 \theta}. 
\]

One observes that one can write

\[
r = \frac{3 \tan \theta \sec \theta}{1 + \tan^3 \theta}, 0 \leq \theta. 
\]

So

\[
A = 9a^2 \int_0^\pi \frac{\tan^2 \theta \sec^2 \theta}{(1 + \tan^3 \theta)^2} d\theta. 
\]

Let \( \tan \theta = t \). Then \( \sec^2 \theta d\theta = dt \), and \( 0 \leq t \leq 1 \). Therefore (32) will be

\[
A = 9a^2 \int_0^1 \frac{t^2 dt}{(1 + t^3)^2}. 
\]

Again one changes the variable. Let \( t^3 = u \). Then \( 3t^2 dt = du \) and \( 0 \leq u \leq 1 \). Finally one has

\[
A = 3a^2 \int_0^1 \frac{du}{(1 + u)^2} = \frac{3a^2}{2}. 
\]
Let $A_n$ be the area of the loop of $A_n$, $n = 1, 2, \ldots$. Then

$$A_1 = \frac{1}{9} A, A_2 = \frac{1}{9^2} A, \ldots, A_n = \frac{1}{9^n} A, \ldots$$

(35)

So the set $\{A_1, A_2, \ldots, A_n, \ldots\}$ is a geometric progression of ratio $\frac{1}{9}$.

Therefore

$$\sum_{n=1}^{\infty} A_n = A \left( \sum_{n=1}^{\infty} \frac{1}{9^n} \right) = \frac{1}{8} A.$$

(36)

So the area of the loop of (1) is eight times the sum of the areas of the loops of its Hessian foliums.

8. THE PARABOLIC CASE

Let one look at (17) again, that is the conic polar of $A(p, q)$ with respect to (1). If (17) is a parabola, then one must have

$$a^2 - 4pq = 0.$$  

(37)

This means that the locus of $A$ for which the polar is a parabola is the equilateral hyperbola

$$xy = \frac{a^2}{4}.$$  

(38)

This idea could be applied to all $A_n$'s, but it is not interesting.

For a fixed $a > 0$, one can give the graph of this hyperbola.

9. ELLIPTIC AND HYPERBOLIC CASES

Again for (17) to be an ellipse one must have

$$a^2 - 4pq < 0$$

(39)

This implies that the locus of $A(p, q)$ is a region of the plane which satisfies

$$xy > \frac{a^2}{4}.$$  

(40)

For $a = 2$, one gets the shaded region of Figure 2.
Similarly, for the polar to be hyperbola one must have

$$a^2 - 4pq > 0. \quad (41)$$

So the locus of $A(p,q)$ is the region

$$xy < \frac{a^2}{4}, \quad (42)$$

which is the unshaded region of Figure 2.

10. THE LENGTHS OF LOOPS

Let one consider the set of loops of $\{A, A_1, A_2, \ldots\}$. Suppose the length of the loop of $A$; that is, the original folium is $s$. Then the length of the loops of $A_1, A_2, A_3, \ldots, A_n, \ldots$ will be respectively

$$\frac{1}{3}s, \frac{1}{9}s, \ldots, \frac{1}{3^n}s, \ldots. \quad (43)$$

This is quite easy to prove, even though obtaining $s$ is quite difficult. Let one call the lengths of these loops respectively $l_1, l_2, \ldots, l_n, \ldots$. Then

$$\sum_{n=1}^{\infty} l_n = s \sum_{n=1}^{\infty} \frac{1}{3^n} = \frac{1}{2}s. \quad (44)$$

One shall write $s$ as an integral.

$$s = 6a \int_0^1 \frac{\sqrt{(1-2t^3)^2 + (2t-t^4)^2}}{(1+t^3)} \, dt. \quad (45)$$
Computing $s$ will be left as an exercise. Note that this section 10 was not studied in Bagchi's paper.

11. The Curvature

Let one look at the set of parametric equations of (1); that is,

$$
\begin{align*}
  x &= 3a \frac{t}{1+t^3} \\
  y &= 3a \frac{t^2}{1+t^3}.
\end{align*}
$$

(46)

The curvature of the curve is obtained from

$$
k = \frac{\frac{dx}{dt} \cdot \frac{d^2y}{dt^2} - \frac{dy}{dt} \cdot \frac{d^2x}{dt^2}}{\left(\frac{dx}{dt} \cdot \frac{d^2y}{dt^2} + \left(\frac{dy}{dt}\right)^2\right)^{\frac{3}{2}}}.
$$

(47)

One shall study the curvature at the node of the curve. This point corresponds to $t = 0$ and $t \to \infty$. Since the curve is symmetrical with respect to the angle bisector of the first quadrant, one only needs to obtain the curvature at $t = 0$. Note that

$$
\begin{align*}
  \frac{dx}{dt} &= 3a \left[\frac{1-2t^3}{(1+t^3)^2}\right] \\
  \frac{d^2x}{dt^2} &= -18a \left[\frac{2t^2-t^5}{(1+t^3)^3}\right] \\
  \frac{dy}{dt} &= 3a \left[\frac{2t-t^4}{(1+t^3)^2}\right] \\
  \frac{d^2y}{dt^2} &= 6a \left[\frac{1-7t^3+t^6}{(1+t^3)^3}\right].
\end{align*}
$$

(48)

So for $t = 0$, one has

$$
\frac{dx}{dt} = 3a, \quad \frac{d^2x}{dt^2} = 0, \quad \frac{dy}{dt} = 0, \quad \frac{d^2y}{dt^2} = 6a.
$$

(49)
This implies that at the node the curvature is \( k = \frac{2}{3a} \), the radius of the curvature is \( \frac{3a}{2} \), and the center of the curvature is at either \((0, \frac{3a}{2})\) or \((\frac{3a}{2}, 0)\). Note that there are two circles of curvature at the node. One of them is

\[
x^2 + (y - \frac{3a}{2})^2 = \frac{9a^2}{4}
\]

or

\[
x^2 + y^2 - 3ay = 0
\]

The case \( a = 1 \) is shown in Figure 3. The other circle of curvature is

\[
x^2 + y^2 - 3ax = 0.
\]

This should explain interesting parts of Bagchi’s paper.

Figure 3.

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LITERATURE CITED

NEW RECORD OF ANTHRACOTHERIIDAE (ARTIODACTYLA: MAMMALIA) FROM THE MIDDLE EOCENE YEGUA FORMATION (CLAIBORNE GROUP), HOUSTON COUNTY, TEXAS

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Abstract.—A small new species of the anthracotheriid artiodactyl genus *Heptacodon* is described from the middle Eocene Yegua Formation (Claiborne Group) from a site near Lovelady, Houston County, Texas. These specimens represent the first record of Eocene anthracotheres in Texas and are the southernmost and easternmost occurrence of the genus. The new species appears to be the most primitive of the four species of *Heptacodon* and provides an opportunity to emend the generic diagnosis of this exclusively North American taxon.

The remains of Eocene land mammals from the Gulf Coast Plain are exceedingly rare (see review in Westgate 2001). Although they are known from other formations within the middle Eocene Claiborne Group, land mammals have not previously been reported from the Yegua Formation. The purpose of this report is to describe an unusual, new occurrence of the anthracotheriid artiodactyl *Heptacodon* from the Yegua Formation in Houston County (100 miles north of the city of Houston and 100 miles east of Waco), Texas, and to focus new attention on this genus, the rarest among North American anthracotheriids.

Anthracotheriids are a family of extinct suiform, bunoselenodont artiodactyls that range in age from middle Eocene to Miocene and occurred throughout the Old World as well as in North America. *Heptacodon* is an exclusively North American genus that was first described from an isolated upper molar by Marsh (1894), and additional species were described by Troxell (1921) and Scott (1940), all from the White River Group of the northern Great Plains. MacDonald (1956) last reviewed the alpha taxonomy of the genus and recognized three species: *H. curtus* in the early Oligocene Upper Brule Formation, and *H. occidentalis* and *H. quadratus* from the late Eocene-early Oligocene Lower Brule Formation, although he admitted that the latter species might fall within the range of variation of the former. MacDonald also reported the first occurrences of the genus outside the White River Group, from the Chadron Formation in Wyoming and South Dakota,
further confirming the presence of the genus during the late Eocene.

More recently, yet earlier records of *Heptacodon* have appeared. Storer (1983) described a small species, *H. pellionis*, from the Lac Pelletier faunas of Saskatchewan which are placed within the late middle Eocene Duchesnean North American Land Mammal Age (NALMA) (Storer 1987; 1996). Fragmentary remains of *Heptacodon* have also been reported in the late middle Eocene (Duchesnean NALMA) Hancock Quarry fauna of the Clarno Formation in Oregon (Hanson 1996) and from the Duchesnean Claron Formation of central Utah (Eaton et al. 1999). Unfortunately, the fossils from Oregon or Utah are not adequate to diagnose to species. Thus, three previously-described species are recognized: the Whitneyan type species *H. curtus*; the Orellan *H. occidentalis*; and the Duchesnean *H. pellionus*. *Heptacodon quadratus*, as noted by MacDonald, appears to fall within the range of variation of *H. occidentalis*. Kron & Manning (1998) noted an undescribed *Heptacodon* from the Gulf Coast of Texas in their overview of North American anthracotheriid distribution, and this important record is described below. Material examined during the course of this study are deposited with the Frick Collection (F:AM) of the American Museum of Natural History (AMNH) in New York.

**SYSTEMATIC PALEONTOLOGY**

Order Artiodactyla  
Family Anthracotheriidae  
Genus *Heptacodon* Marsh 1894


**Type species.**— *Heptacodon curtus* Marsh 1894.


**Occurrences.**— Duchesnean of Saskatchewan, Oregon, Texas and Utah; Chadronian of Wyoming, South Dakota and Colorado; Orellan and Whitneyan of South Dakota.

**Emended diagnosis.**— *Heptacodon* differs from other Paleogene anthracotheriids in having a fused mandibular symphysis without trace of suture (unfused in most anthracotheriids), P/2 postprotocristid more buccally positioned and a slight central swelling along molar cristid
obliqua. Differs from the Asian genera Anthracothema, Anthracokeryx, Siamotherium and Anthracosenex in possessing a postentocristid, having a broken hypolophid and lacking an anterior protolophid. Differs from Anthracokeryx, North American Bothriodon, Aepinacodon and Arretotherium, and Euro-American Elomeryx and African Bothriogenys in possessing a strong postprotocristid, tooth rows without significant diastemata between canine and P/1 and/or P/1-P/2, relatively simple P/2-P/3 with posterior cingulid slight, P/4 only slightly elaborated by a strong protocristid and lacking posterior cingulid, premolar lingual cingula absent, molar paracristid ending near base of metaconid and unconnected to anterior cingulum, and molar postentocristid weak (H. curtus) to absent (other sp.). Further differs from Elomeryx, Bothriodon, Aepinacodon and Arretotherium in having a compressed (rather than open) mesostyle and lower crown height.

Heptacodon yeguaensis, new species

Figure 1b,c,f

Holotype.—F:AM 42984, left M2/ (Fig. 1c).

Paratype.—F:AM 42985, right M3/ (Fig. 1b and f).

Type Locality.—"Loc. 3, Lovelady, Houston County, Texas, Yegua Formation" (data from specimen tag).

Type Horizon.—stratigraphic position unknown, middle Eocene Yegua Formation, Claiborne Group.

Diagnosis.—Differs from all other Heptacodon (where known) in its smaller size and in having a moderately-developed mesiobuccal cingulum on the upper molar parastyle and relatively greater buccal projection of parastyle. Further differs from H. curtus and is similar to H. occidentalis and H. pellionus in retaining a relatively stronger hypolophid on the molars and having a weakly-developed preentocristid.

Description.—F:AM 42984, a left M2/ or possibly M3/, is a low-crowned five-cusped tooth (Figure 1c). It measures 15.1 mm in maximum length, 14.5 mm long at the midline and 19.8 mm in maximum width. Assignment as an M2/ is most likely. The metastyle is poorly developed. In most anthracotheriids the metastyle is at least moderately developed on M3/ in order to occlude with the posteriorly-extended M/3 hypoconulid (e.g., as in AMNH 1039, Fig. 1a). However, since a posterior wear facet is lacking on this tooth and M2/ and M3/ are not markedly different in size in known Heptacodon sp., it is
Figure 1. *Heptacodon* sp., shown to demonstrate differences among species of *Heptacodon*. All specimens except 1b are shown coated with ammonium chloride, and all scale bars = 5 mm. (a) *H. occidentalis*, AMNH 1039, a left maxilla with P2/-M3/, from the Orellan Scenic Member of the Brule Formation, South Dakota; (b) *H. yeguaensis*, F:AM 42985, right M/3 in medial (lingual) view; (c) *H. yeguaensis*, F:AM 42984, left M2/; (d) *H. curtus*, F:AM 105170, right M/3, from Whitneyan Poleslide Member of the Brule Formation, South Dakota; (e) *H. occidentalis*, AMNH 1360, right M/3, from Orellan Scenic Member of the Brule Formation, South Dakota; (f) *H. yeguaensis*, F:AM 42985, right M/3 in occlusal view.
not possible to exclude the possibility that F:AM 42984 is an M3/ of this species. If so, H. yeguaensis would also be characterized by an unusually small M3/ metastyle.

The paracone and metacone are subequal in size with metacone positioned slightly toward the midline (lingual). Both cusps bear strong buccal ridges, better developed on the paracone than the metacone. The metastyle is tall, well-developed and cuspidate. It projects buccally beyond the bases of buccal cusps. The parastyle is larger, projecting buccally and distally with a slight crest atop it having a principally distal (rather than buccal) orientation. A moderately-developed cingulum is present on the buccal surface of the parastyle. This cingulum extends mesiad and sharply "ascends" to terminate near the occlusal surface. A well-developed and beaded (where unworn) anterior cingulum is present, extending lingually from near the midline and terminating near the base of the protocone. The protoconule is moderately developed and is approximately one-half the size of the major cusps. It is placed equidistant between the paracone and protocone. The metaconule is pyramidal in shape with a moderately developed premetacrista that is mesiolingually directed to join the slight lingual cingulum between protoconule and metaconule. A posterior cingulum extends from the base of the metaconule to the base of the metacone.

Wear is strongest on the mesial faces of the cusps and crests, rendering the paraconule confluent with the protocone, and the postprotoconule cristae is nearly obliterated. The buccally-oriented pre- and postmetaconule cristae are worn.

F:AM 42985, a right M3/, is a five-cusped tooth (Figure 1b, f), measuring 21.7 mm in maximum length, 11.75 mm maximum width and with the hypoconulid alone measuring 6.65 mm in length and 7.33 mm in width, which is 18% shorter and 11% narrower than Heptacodon pellionus, the next smallest species of the genus. Enamel is missing on the posterior face of the protoconid and mesiobuccal corner of the protoconid, and the posterior half of the hypoconid is missing. The trigonid is formed by subequal protoconid and metaconid with the protoconid slightly mesiad of the metaconid. The paracristid is strong, descending the face of the paraconid in a shallow arc, terminating near the middle of the metaconid’s base and a few millimeters above the slight anterior cingulum. The metaconid and protoconid are joined by a moderately straight protolophid, and there is a strong postmetacristid.
The trigonid is slightly wider than the talonid. The cristid obliqua is strong and high, taking a sinuous course across the talonid basin to ascend the posterior trigonid wall just lingual of the midline. A slight swelling is present near the center of the crest. The entoconid and hypoconid are joined by a V-shaped posterior hypocristid and posterior entocristid. The hypolophid is discontinuous and is better developed in its buccal half. The "heel" of M/3 is formed by a well-developed hypoconulid. The "loop" begins at the midline and terminates just posterior to the entoconid’s base, leaving the hypoconulid basin lingually open. Very slight buccal cingulids are present between hypoconulid and hypoconid and between hypoconid and protoconid.

Compared with *Heptacodon curtus* (Figure 1d) and *H. occidentalis* (Figure 1e), the M/3 is relatively narrower with respect to length, and the crests are more weakly developed. In most respects, the M/3 of *H. yeguaensis* appears to be a scaled-down version of its much larger relatives. However, like *H. occidentalis* and *H. pellionus* (not figured) it still retains a hypolophid, which is largely lost in *H. curtus*, and has a weak preentocristid, which is strongly developed in *H. curtus*.

**Etymology.**—This species is named for the Yegua Formation from which it was collected.

**DISCUSSION**

Although poorly known, *Heptacodon yeguaensis* appears to be the most primitive of the known species of *Heptacodon*. The retention of a lingual portion of the hypolophid on M/3, a lower molar preentocristid, and a buccal cingulum on the upper molar are primitive features that are shared with other, earlier Paleogene anthracotheriids. These features are also more primitive than the condition observed in *Heptacodon* specimens from known Duchesnean and Chadronian sites (where comparable).

This record is the first for this genus in the southern United States as well as its easternmost occurrence. This species may also represent the oldest occurrence of the genus in North America, but its precise relative age is difficult to determine for several reasons. The Yegua Formation is well constrained through micropaleontological analyses to approximately two million years of the late middle Eocene, spanning the entirety of planktonic foraminiferal zone P14 and part of P15 (Meckel and Galloway 1996). Based on correlation of these zones to the
Geomagnetic Reversal Time Scale (Aubry et al. 1988), these zones correspond to Chrons 18n and the lower part of Chron 17r. Based on the latest attempts to determine the placement of the Uintan-Duchesnean boundary (Prothero 1996; Prothero et al. 1996), the interval spanned by the Yegua Formation would correspond to the latest Uintan and much of the Duchesnean. However, the precise stratigraphic position of the type locality within this formation has not yet been determined. The type and referred specimen were collected in 1936 by Claude Riley from a site near Lovelady, Houston County, Texas, but its precise location and stratigraphic position within the formation is not known. Other fossils collected with the mammal teeth include a dermemydid turtle and an ariid catfish, which do not provide any additional evidence for the age of the locality. This limited evidence, combined with the Duchesnean age of faunas from the overlying Jackson Group, is suggestive of an early Duchesnean age assignment for the Lovelady fossils. However, an older or slightly younger age cannot be eliminated on available evidence.

*Heptacodon yeguaensis* also provides a frustratingly incomplete addition to the knowledge of Eocene mammals on the Gulf Coastal Plain. As recently reviewed by Westgate (1986; 1990; 2001) the knowledge of Eocene mammal evolution on the Gulf Coast Plain is principally from the Uintan Casa Blanca local fauna of Texas. The remainder of sites and faunas, like that described here from near Lovelady, represent only isolated occurrences, hinting at the tropical faunas that once thrived along the ancient Texas shore.

**ACKNOWLEDGMENTS**

Earl Manning first recognized the anthracotheriid affinities of the material described here, and I thank Malcolm McKenna for suggesting that I examine these fossils. Funding for museum work was provided from the Annie M. Alexander Endowment. Jon Baskin and James Westgate provided helpful reviews. This is University of California Museum of Paleontology contribution #1790.

**LITERATURE CITED**


Hanson, C. B. 1996. Stratigraphy and vertebrate faunas of the Bridgerian-Duchesnean...


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ICHNOLOGY, STRATIGRAPHY AND PALEOENVIRONMENT OF
THE BOERNE LAKE SPILLWAY DINOSAUR TRACKSITE,
SOUTH-CENTRAL TEXAS

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Abstract.—Record flooding in late June 1997 in south central Texas exposed dinosaur
footprints on the Boerne Lake spillway near Boerne, Texas. At least three trackways are
present in the upper portion of Unit No. 3 of the Lower Cretaceous Glen Rose Formation.
This sequence represents a period of high-frequency depositional cyclicity on a very shallow
and partly restricted inner shelf. The track-bearing layer exhibits features characteristic of
sabkha-like tidal flats subject to subaerial exposure. It is overlain and underlain by red clay
horizons of secondary origin. Those dinosaur prints exhibiting sufficient morphologic
preservation to be identifiable appear to have been made by a theropod (carnivorous)
dinosaur. Other footprints were too poorly preserved to permit identification of the
trackmakers more specifically than as bipedal dinosaurs.

Record flooding in south central Texas resulted in four deaths and
several million dollars in property damage in late June of 1997. When
the flood waters receded, erosion had removed vegetation, soil and
bedrock, necessitating repair to the emergency spillway at Boerne Lake
near Boerne, Texas. When Natural Resources Conservation Service
officials surveyed the damaged area, they discovered newly exposed
dinosaur tracks on the floor of the spillway.

Geologists from Baylor University, the University of Texas at San
Antonio and Indiana University-Purdue University Fort Wayne investi¬
gated the site. In cooperation with city, county and federal officials,
they attempted to keep the site location concealed until the tracks could
be documented. However, the news media learned of the site and
turned the discovery into a TV and newspaper mass media event with
national news coverage.

LOCATION

Boerne Lake is located approximately 0.5 miles west of Interstate
Highway 10 at the Ranger Creek exit just northwest of Boerne, Texas
(Fig. 1). The spillway is located along the southeast corner of this lake,
which provides potable water to the City of Boerne. The tracks lie in thin-bedded limestone in the upper third of the spillway.

METHODS

Following an initial evaluation of the site, flood detritus and remnants of the overlying red clay were removed using small hand tools. Photodocumentation included oblique photos of the three well-preserved trackways from multiple perspectives. Each individual footprint was also photographed from directly overhead to capture the track shape as preserved.

A detailed footprint map was created by laying out a chalk line grid on the track layer at five foot intervals with the axes corresponding to magnetic N/S and E/W directions as determined in the field with a Brunton compass/clinometer. Individual footprint centers were measured relative to this grid, yielding north-south and east-west coordinates for
the center of each print. These coordinates were input into a CADD program to develop the base map. Individual footprint bearings as measured with the Brunton were utilized to orient the tracks on the map relative to magnetic north.

Footprint measurements were made in accordance with standard protocols (e.g., Leonardi 1987; Thulborn 1990; Lockley 1991; Farlow & Galton 2002). Footprint lengths were measured from the rear margin ("heel" - actually the back of the toe region of these digitigrade animals) of the print to the tip of the middle toe (digit III). Footprint widths were measured across the tips of the inner and outer toes. Maximum footprint depths were measured both in the toe region and in the rear ("heel") portion of the print.

Individual footprint compass bearings were sighted from the rear margin of the print to the tip of digit III. The averages of the bearings of a particular footprint and the print preceding it, and also of the footprint and the print following it, were taken to indicate the overall direction of travel of the dinosaur during the two steps. The bearing of a given footprint could then be compared with these two estimates of the animal's direction of travel. Footprint rotation with respect to the preceding print compares the inward (toward the trackway midline) or outward (away from the trackway midline) orientation of a particular footprint relative to an overall direction of travel estimated as the average of the bearings of the print in question and the preceding footprint. Footprint rotation with respect to the following print uses an overall direction of travel estimated from the print in question and the following footprint. By convention (Leonardi 1987) negative values indicate that the footprint toes inward, and positive values indicate outward footprint rotation. A zero value indicates that the footprint bearing coincides with the dinosaur's direction of travel.

Trackway paces denote the distance from a given print to the next print made by the opposite foot, and strides refer to the distance from a given print to the next print made by the same foot. When possible, paces and strides were measured using the tip of a footprint's digit III as the reference point; where this was not possible, the centers of footprints were utilized. From the pace ending in a particular footprint, the pace beginning with that footprint, and the stride opposite the footprint (made as the opposite foot was brought forward), the pace angulation around the footprint was calculated using the law of cosines. This
indicates the linearity/narrowness of the trackway; a pace angulation of 180° means that footprints of the left and right side of the body fall on a single line, a very narrow trackway. With increasingly narrow trackways the value of the pace angulation is sensitive to slight errors of measurement. If the measured stride is greater than the sum of the two paces opposite it, the pace angulation cannot be calculated. In such cases the pace angulation was estimated as ≈ 180°.

Casts of selected footprints were made and topographically digitized to evaluate print morphology. Utilizing this information, contour maps of the footprints were created.

Stratigraphic field investigative methods included measuring and describing the section at the site, field correlation with local marker beds of the upper Glen Rose Formation exposed at adjacent cliff outcrops, photo-documenting stratigraphic features of the site and surrounding area, and sampling select horizons for further analysis. Field correlations to adjacent outcrops were performed visually. The flat-lying nature of the beds of the Glen Rose Formation facilitated gross correlations between outcrops, as did the appropriate topographic and geologic maps (U.S.G.S. 1964; Texas Bureau of Economic Geology 1982).

**GEOLOGIC SETTING**

Structurally the site lies south of the Llano Uplift and the associated San Marcos Arch, both of which were positive structural features during the Cretaceous Period (Adkins 1932). These two features appear to have been primary controls of the depositional and structural setting of the site, creating a broad area of shallow-water and shoreline deposition in the encroaching Trinity Sea (Stricklin et al. 1971).

The shallow shelf of central Texas during early Cretaceous time exhibited a cyclically transitional shoreline and shallow marine environment along an epeiric sea. Typical environments included streams, marshes, tidal flats, lagoons and shallow subtidal marine environments. Deposition occurred primarily in shallow water, with frequent subaerial exposure. Isolated rudist and coral patch reefs occurred commonly in the shallow waters, with shelf margin reefal facies occurring farther southeast along the developing Stuart City Reef Trend (Stricklin et al. 1971).
DESCRIPTION OF THE BOERNE LAKE SPILLWAY TRACKSITE

The site occurs on the gently sloping spillway formed of thinly bedded, horizontal limestone layers. Much of the face is covered with flood debris. The active portion of the spillway during the flood was denuded of vegetation.

Dinosaur prints exposed on the spillway of Boerne Lake occur in thinly bedded limestones in the upper Glen Rose Formation of the Lower Cretaceous Trinity Group, about 40 m above the "Corbula bed" that marks the top of the lower Glen Rose (Fig. 2). This stratigraphic position corresponds to the upper part of Unit 3 of the upper Glen Rose (Stricklin et al. 1971). This is considerably higher in the Glen Rose Formation than the common track-bearing layers, which lie a few meters below the Corbula zone (Stricklin et al. 1971; Stricklin & Amsbury 1974).

The Boerne Lake Spillway tracksite is within the upper third of a 4.4-m-thick cyclic interval of thinly bedded wackestone and nodular clayey wackestone, which represents shallow-subtidal to tidal-flat deposition. Fossils in this unit include abundant thin-shelled oysters, other small bivalves, thin, high-spired gastropods, orbitolinids, miliolids and ostracodes. Cyanobacterial stromatolites, mud-cracked layers, and horizontal dissolution cavities (probably dissolved evaporite layers) are associated with the dinosaur prints. The upper meter contains two bored hardground surfaces.

The track-bearing lithologic unit represents a period of high-frequency depositional cyclicity on a very shallow and partly restricted inner shelf. During a period of lowest sea level, when the sabkha-like tidal flats prograded farthest seaward, dinosaurs were able to move through the area. While not necessarily diagnostic of tidal flat deposition, it is nonetheless characteristic of many Lower Cretaceous dinosaur footprints in Texas to occur in such environments.

This upper interval of Unit 3 rests on a well-defined bored and oyster-encrusted hardground at the top of a 2-m-thick burrowed wackestone containing some requinid and monopleurid rudists (probably equivalent to the "Massive" marker bed of Unit 3 of Stricklin et al. 1971). Just below this, the upper Glen Rose is predominantly clay with abundant orbitolinids, probably representing a slightly deeper and open inner shelf.
Figure 2. Stratigraphic position of the Boerne Lake Spillway dinosaur tracksite. The approximate location of the contact between units 3 and 4 of Stricklin et al. (1971) in the Boerne Lake Spillway section is indicated.
Figure 3. Diagrammatic map showing disposition of the better-preserved dinosaur footprints at the Boerne Lake Spillway tracksite (some of the footprints of the trackways for which measurements are given in Tables 1 and 2 are not depicted due to poor preservation). The interval between each tic mark along the horizontal and vertical margins of the map is one foot; mesh size of the lines in the grid is five feet. Letter labels designate trackways, and numbers individual footprints within those trackways. The OA sequence is the best-preserved trackway. The OD footprints were initially thought to constitute a single trail, but are presently interpreted as made by two animals (see Table 1 for assignment of prints to the two trackways). The OB and OC prints may represent trackways (with OB a possible continuation of OA), but were not well enough preserved to warrant measuring.
Immediately overlying the tidal-flat and hardground layers of upper Unit 3 is about a meter's thickness of clay containing echinoids, bivalves, gastropods and green algae, representing a return to more open, normal-marine conditions. This fossiliferous clayey interval is probably the basal layer of Unit 4 as defined by Stricklin et al. (1971).

**Dinosaur Footprints**

Although the track-bearing surface is covered with numerous depressions that might have been footprints, most of these are so poorly preserved that nothing can be said about the number and kinds of animals responsible for them. Three sets of footprints can unambiguously be associated in trackways, however (Fig. 3).

A large bipedal dinosaur made Trackway OA. None of the footprints in the trackway is well preserved. The average footprint length in this trail is about 49 cm, and the average width about 43 cm (Table 1). Footprints of greater length than width are usually interpreted as having been made by theropod dinosaurs (Moratalla et al. 1988; Thulborn 1990; Lockley 1991). Although some of the prints have relatively short, thick toes (Figs. 4, 5), a feature typical of prints attributed to ornithopods (Thulborn 1990; Farlow & Chapman 1997), the best preserved footprint in the trackway shows rather longer, narrower toes, giving it a more theropod-like appearance (Farlow 1987; Pittman 1989; Hawthorne 1990). Consequently the ornithopod-like gestalt of most of the prints in the trackway is likely an artifact of preservation, and the trackmaker is identified as a large theropod. The size of the prints is comparable to those of footprints attributed to large theropods at other Glen Rose tracksites (Farlow 1987; 2001; Pittman 1989).

The maker of trackway OA moved in a northerly direction across the site, making sharp changes in direction twice (Fig. 3). Over the interval of prints OA5 through OA7 the dinosaur abruptly turned to the right, and after making print OA17 it turned less sharply to the left. The pace angulation is generally high over the length of the trail (Table 2), as is typical for trackways of bipedal dinosaurs (Farlow & Chapman 1997), but the two abrupt changes of direction resulted in abnormally low values of the pace angulation. The dinosaur’s footprints usually toe slightly inward (slightly negative footprint rotation), as is typical of Comanchean tridactyl footprints attributed to theropods (Farlow 1987).
Table 1. Measurements of individual Boerne Lake Spillway dinosaur footprints.

<table>
<thead>
<tr>
<th>Trackway</th>
<th>Footprint</th>
<th>Symmetry (Left or Right)</th>
<th>Footprint Length (cm)</th>
<th>Footprint Width (cm)</th>
<th>Toe Depth (cm)</th>
<th>&quot;Heel&quot; Depth (cm)</th>
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<td>OA1</td>
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<td>13.1</td>
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| OD1      | OD8 (1st print) | ? | ? | ? | ? | ? |
| OD6      | OD2 (2nd print) | ? | 30.5 | 30.5 | 7.6 | 7.6 |
| OD2      | OD7 (1st print) | ? | ? | ? | ? | ? |
| OD5      | OD3 (3rd print) | ? | 33.5 | 30.5 | 9.1 | 9.1 |
| OD3      | OD4 (4th print) | ? | 33.5 | 30.5 | 6.1 | 6.1 |
| OD1      | OD2 (2nd print) | ? | 33.5 | 30.5 | 6.1 | 6.1 |
| OD-1     | OD3 (5th print) | ? | ? | ? | ? | ? |
| OD-2     | OD4 (5th print) | ? | 25.9 | 21.3 | 4.6 | 7.9 |
| OD-3     | OD5 (6th print) | ? | 27.4 | 25.9 | 7.6 | 6.7 |

Trackmaker OA moved in a leisurely fashion. The average stride is about 242 cm, roughly five times the length of individual footprints in the trail. This is toward the low end of stride/footprint length ratios observed in Glen Rose theropod trackways (Farlow 1987).

What are interpreted as trackways (OD1, OD2) of two smaller bipedal dinosaurs cut across trail OA at the northern end of the latter trail (Table 2; Figs. 3, 4d). Conceivably OD1 and OD2 constitute the trackway of a single animal with a rather broad straddle and a very low pace angulation; "wide-gauge" trackways attributed to theropod dinosaurs are known from the Jurassic (Lockley et al. 1996; Day et al. 2002). However, unambiguous wide-gauge trackways of bipedal dinosaurs have yet to be found in the Glen Rose Formation, where narrower trackways are common (Farlow 1987), and so it appears more likely that these are
Figure 4. Photographs of dinosaur footprints and trackways of the Boerne Lake Spillway tracksite. A-C: Trackway OA. (A) Oblique view of a portion of the trackway, beginning with footprint OA7; the dinosaur was moving away from the viewer. (B) Footprint OA7 (a right). (C) Footprint OA15 (a right). (D) Oblique view of the two OD trackways; the dinosaurs were moving toward the viewer. Footprints OD2 and OD0 of one of the OD trackmakers are to the left of the meter stick, and print OD1 of the other OD trackmaker is to the right of the meter stick. The trackway of the large OA dinosaur crosses the trails of the two smaller animals, moving from right to left; print OA16 of the big dinosaur is at the end of the meter stick toward the viewer.
Figure 5. Topographic maps of footprints from trackway OA. Sizes of footprints are indicated by centimeter scales along the vertical and horizontal margins of the maps. (A) Footprint OA7 (a right). The topographic map was made from a cast (negative copy) of the footprint, and so left-right symmetry and topography are reversed from the actual footprint. Although the footprint has a shape reminiscent of prints attributed to ornithopods, note the suggestion of a clawmark on digit IV (the leftmost toemark in the topographic map). (B) Footprint OA15 (a right). In this case the topographic map was made from a positive copy of the footprint, and so topography and symmetry are the same as in the actual footprint. This footprint suggests longer and narrower, more typically theropod-like toes.
### Table 2. Measurements of Boerne Lake Spillway dinosaur trackways.

<table>
<thead>
<tr>
<th>Trackway</th>
<th>Reference Footprint</th>
<th>Footprint Bearing (degrees; 0° = North)</th>
<th>Footprint Rotation (degrees) with Respect to:</th>
<th>Pace Length</th>
<th>Stride Opposite the Footprint</th>
<th>Pace Angulation (degrees)</th>
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</thead>
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<td></td>
<td></td>
<td>Preceding Print</td>
<td>Following Print</td>
<td>Ending in Print</td>
<td>Beginning with Print</td>
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<tr>
<td>OA</td>
<td>OA1</td>
<td>320</td>
<td>-</td>
<td>133.5</td>
<td>118.9</td>
<td>248.4</td>
</tr>
<tr>
<td></td>
<td>OA2</td>
<td>328</td>
<td>4</td>
<td>112.9</td>
<td>118.9</td>
<td>237.7</td>
</tr>
<tr>
<td></td>
<td>OA3</td>
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<td>3</td>
<td>120.7</td>
<td>114.0</td>
<td>232.3</td>
</tr>
<tr>
<td></td>
<td>OA4</td>
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<td>-1</td>
<td>135.6</td>
<td>130.1</td>
<td>258.5</td>
</tr>
<tr>
<td></td>
<td>OA5</td>
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<td>-6</td>
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<td>167.6</td>
<td>249.0</td>
</tr>
<tr>
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<td>135.6</td>
<td>180.0</td>
</tr>
<tr>
<td></td>
<td>OA7</td>
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<tr>
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</tr>
<tr>
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<td>-</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
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<td>-</td>
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</tr>
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<td></td>
<td>OD5</td>
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<td>-</td>
<td>-</td>
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<td>-</td>
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<tr>
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<td>OD-5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>111.9</td>
<td>-</td>
</tr>
</tbody>
</table>
Figure 6. Topographic map made from a positive copy of footprint OD3 (a left?) of trackway OD2.

trails made by two animals. Most of the footprints in the two trails are little more than vague holes in the ground, but the better-preserved tracks, such as they are, suggest a tridactyl foot (Fig. 6). These are not well enough preserved, however, for proper identification of the trackmakers any more precisely than as bipedal dinosaurs. Both trails have pace angulations typical of bipedal dinosaurs (Farlow 1987), and in both trails the stride/footprint length ratio is about 7-8, toward the high end for trails that were likely made by walking (as opposed to running) dinosaurs (Farlow & Chapman 1997). The two trackways are close together, and roughly parallel. If the two sets of prints were indeed made by two dinosaurs, and if they were made at the same time, the two animals may have been walking side by side.

Although there is significant variability in footprint depth within each of the three trackways (Table 1), the deepest footprints at the site were made by trackmaker OA, the biggest of the three dinosaurs (Fig. 7). Thus footprint depths at the site may not reflect circumstances of preservation alone, but also differences in body weights of the trackmakers. Prints with deep toe regions also tended to have deep "heels", and so there was no systematic variability in depth along the fore-aft axis of the footprints (fig. 7).
Figure 7. Footprint depth relationships. (A) The biggest dinosaur unsurprisingly made the deepest footprints. (B) Footprint depths were consistent between the toe and "heel" regions of prints.

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section and the depositional environment analysis, and reviewed the text. Jim Whitcraft assisted in the preparation of artwork. Our project was supported by a grant from the National Science Foundation to J. O. Farlow. This paper is dedicated to the memory of two colleagues: William A. S. Sarjeant, whose research on footprints of extinct vertebrates set a high standard for all who follow, and David L. Amsbury, whose studies of the stratigraphy and sedimentology of the Texas Cretaceous played a key role in our understanding of these topics.

**LITERATURE CITED**


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MODELING SURVIVAL FOR UNTHINNED SLASH PINE PLANTATIONS IN EAST TEXAS UNDER THE INFLUENCE OF NON-PLANTED TREE BASAL AREA AND INCIDENCE OF FUSIFORM RUST

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Box 6109 SFA Station, Nacogdoches, Texas 75962

Abstract.—A stand level survival model for unthinned slash pine (Pinus elliottii) plantations in east Texas was developed that incorporates density of non-planted tree basal area per hectare competition and the incidence of fusiform rust (Cronartium quercuum). Survival data on planted slash pine trees were collected on 197 permanent research plots that represent a broad range of site, age, and competitive status combinations. A system of two equations was fit to the survival data using simultaneous nonlinear regression. All model parameters were significant at the 0.05 probability level. The model showed that the number of surviving planted slash pine trees decreased with increasing density (trees per hectare) of non-planted trees as well as increasing site quality (site index). The model further allowed the transition of the slash pine trees from being uninfected to being infected by fusiform rust.

Infection of pine plantations with fusiform rust (Cronartium quercuum [Berk.] Miyabe ex Shirai f. sp. fusiforme) causes serious problems for forest owners in the southern United States. An estimation of the annual financial loss from rust associated mortality in slash pine (Pinus elliottii Engelm.) and loblolly pine (Pinus taeda L.) plantations in the southern United States is 28 million dollars (Adams 1989). This includes death from girdling of the tree by the rust canker as well as incremental mortality from wind breakage, insect infestation, and other causes that exert additional stress on the already weakened condition of infected trees. Lenhart et al. (1994) reported that an average of 40% of east Texas slash pine trees had stem cankers caused by fusiform rust.

Competition for site resources from non-planted trees has also contributed to the mortality of planted pine trees (Stewart et al. 1984; Shiver et al. 1990; Haywood & Tiarks 1990; Glover & Zutter 1993; Fortson et al. 1996). These studies found significant negative growth effects of competing vegetation on the planted pine trees.

The incidence of fusiform rust and competition from non-planted trees must be considered in any prediction of future growth and yield for pine
plantations. A primary component in the accurate prediction of future plantation growth and yield is the number of trees per unit area expected to survive to a harvestable age. Future yields are dependent on the number of trees per unit area in conjunction with other useful predictors, such as plantation age, tree height, site index, basal area, and average tree size.

Several approaches to predicting the surviving number of trees in pine plantations have been developed (Clutter & Jones 1980; Bailey et al. 1985; Clutter et al. 1984; Lenhart 1972; Somers et al. 1980), but none of these approaches directly considered non-planted tree competition or the incidence of fusiform rust. Burkhart & Sprinz (1984) and Burkhart et al. (1987) did include the effects of hardwood competition in estimating the surviving number of planted pines. They found significant negative effects of hardwood competition in estimating the surviving number of planted pines. However, they did not directly consider the effects of fusiform rust.

Devine & Clutter (1985) developed equations that predicted survival for slash pine trees that were either infected or not infected by fusiform rust. One survival equation was computed for uninfected trees, and another survival equation was computed for infected trees that included the additive effects of mortality associated with fusiform rust. Adams (1989) developed survival models for trees infected and uninfected with fusiform rust that allowed for the transition of trees from an uninfected stage to an infected stage. Multinomial logistic regression models were developed by Arabatzis et al. (1991) to predict the possible transition paths of planted loblolly pine trees from a live to dead status. Stem infection by fusiform rust was one of the stages along the transition paths. However, none of these studies directly incorporated the effects of non-planted tree competition on the survival of planted pine trees.

The objective of this study was to develop prediction equations to estimate the surviving number of planted slash pine trees growing under the influence of non-planted tree competition and fusiform rust. These equations are applicable to unthinned slash pine plantations located throughout east Texas.

**Materials and Methods**

*Slash pine plantation measurements.*—Long-term data from 197 East Texas Pine Plantation Research Project (ETPPRP; Lenhart et al. 1985)
permanent research plots located in slash pine plantations across east Texas were analyzed in this study. The ETPPRP study area covers 22 counties across east Texas. Generally, the counties are located within the rectangle from 30° - 35° north latitude and 93° - 96° west longitude. Each plot consists of two adjacent subplots separated by an 18.3-meter buffer. Within a subplot, the 15-year survival status (live or dead) was monitored for each planted slash pine tree. In addition, the numbers of non-planted trees (volunteer pine and hardwoods) within two embedded 0.002314 hectare circular plots (radius = 2.7 meters) in each subplot were monitored for 12 years.

In this study, one subplot per study plot was randomly selected for model fitting, and the other subplot was utilized for model evaluation. Minimum plantation age was set at 5 years because of inconsistent determination of main stem fusiform rust incidence in young (<5 years) plantations. As a result, the 197 slash pine subplots were used for model fitting and 194 slash pine subplots were used for model evaluation.

Mean plantation age and site index values (base age = 25 years; Lee 1998) are similar for both evaluation and development subplots. On the average, about 34% of the slash pines had stem cankers from fusiform rust (Table 1).

Survival models.—Adams (1989) developed survival models for fusiform rust infected and uninfected pine trees that allow for the transition of trees from an uninfected stage to an infected stage. His work was based on Shapiro’s (1946) differential equations, which are used to describe the growth of two different bacteria types (X, Y). These two populations increase not only by cell divisions resulting in the same type (e.g., X dividing to yield X), but also by mutation (e.g., X mutation to Y). Shapiro’s (1946) equations are:

\[
\frac{dx}{dt} = ax + by \\
\frac{dy}{dt} = mx + cy
\]

(1)

where:

\[ a, c = \text{population growth rates}, \]
\[ b, m = \text{mutation rates}. \]
Table 1. Observed stand characteristics for east Texas unthinned slash pine plantations data sets. AGE = plantation age (years), S = site index (meters), TPH = total trees per hectare, \( N_u \) = number of trees per hectare without a fusiform rust stem gall, \( N_i \) = number of trees per hectare with a fusiform rust stem gall, PBA = planted slash pine basal area (m²/ha), NPTB = non-planted tree basal area (m²/ha), and RNTB = ratio of the non-planted tree basal area to total basal area per hectare.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Mean</th>
<th>Std Dev.</th>
<th>Min.</th>
<th>Max.</th>
<th>Mean</th>
<th>Std Dev.</th>
<th>Min.</th>
<th>Max.</th>
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<td>7</td>
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<td>13.5</td>
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<td>7</td>
<td>26</td>
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<td>0.09</td>
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<td>0</td>
<td>0.70</td>
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</tbody>
</table>

Adams (1989) modified Shapiro's equations (1) to consist of two components: surviving trees infected with fusiform rust (\( N_i \)) and surviving trees uninfected with fusiform rust (\( N_u \)):

\[
\frac{dN_i}{dA} = -(\rho_i + \gamma)N_i + \phi N_u
\]

\[
\frac{dN_u}{dA} = \gamma N_i - (\rho_u + \phi)N_u,
\]

where:

\( \rho_i \) = instantaneous mortality rate for infected trees,

\( \rho_u \) = instantaneous mortality for uninfected trees and,

\( \phi \) = instantaneous rate of uninfected trees becoming infected, and

\( \gamma \) = instantaneous rate of infected trees becoming uninfected = 0.

After a period of time (dA), the numbers in each group will change (d\( N_i \) and d\( N_u \)). The number of trees in the infected group will decrease due to mortality at the rate \( \rho_i \), but will gain the number of uninfected trees that become infected during this time at the rate \( \phi \). Mortality and a change in uninfected status at the rates \( \rho_u \) and \( \phi \), respectively, will both decrease the number in the uninfected component. The
parameter $\gamma = 0$ because there is no possibility of infected trees becoming uninfected.

Adams' equations can be solved (Lee & Coble 2002) via the Method of Determinants (Grossman & Derrick 1988). The resulting equations are expressed as the change in numbers of slash pine trees between two time periods, $A_1$ and $A_2$:

\begin{align}
N_{i2} &= \beta N_{u1} e^{-\alpha(A_2 - A_1)} + (N_{i1} - \beta N_{u1}) e^{-\rho(A_2 - A_1)} \\
N_{u2} &= N_{u1} e^{-\alpha(A_2 - A_1)},
\end{align}

where:

$A_2$ = projection age (years),

$A_1$ = initial age (years),

$N_{i2}$ = number of surviving infected trees per hectare at $A_2$,

$N_{i1}$ = number of surviving infected trees per hectare at $A_1$,

$N_{u2}$ = number of surviving uninfected trees per hectare at $A_2$,

$N_{u1}$ = number of surviving uninfected trees per hectare at $A_1$, and

$\alpha, \beta, \rho_1$ = parameters to be estimated.

Equations (3) provide for separate estimates of mortality rates for infected and uninfected slash pine trees, as well as the possible transition from an uninfected to infected status. The parameter $\alpha = (\rho_u + \phi)$ is the rate at which trees are lost from the uninfected class. The parameter $\beta = \frac{\phi}{\rho_1 - \alpha}$ represents the proportion of uninfected trees that become infected, some of which are lost at the rate, $\alpha$. Behavior of this model is consistent with the desired properties of path invariance and convergence; the number surviving planted pine trees converge to zero as age goes to positive infinity.

Adams (1989) and Adams et al. (1996) reported that pine survival in their studies decreased as site productivity (as measured by site index)
increased. The faster rate of stand development in plantations (and natural forests) of higher site productivity triggers competition-induced mortality at earlier ages than in plantations of lower site productivity (Oliver and Larson 1996). Thus, the number of surviving trees at any plantation age will be lower in plantations of higher site productivity versus plantations of lower site productivity.

As mentioned earlier, the competitive effects of non-planted trees may also influence pine survival. So, a combined variable for the ratio of non-planted tree basal area to total basal area per hectare (RNTB) and site index (S) in meters (base age = 25 years) was incorporated into the differential equations (2) of Adams (1989) and solved in a similar manner as before (subject to the assumption that RNTB is constant with respect to age; see discussion below):

\[
N_{i2} = \beta N_{u1} e^{-\alpha S RNTB (A_2 - A_1)} + (N_{i1} - \beta N_{u1}) e^{-\alpha S RNTB (A_2 - A_1)}
\]

\[
N_{u2} = N_{u1} e^{-\alpha S RNTB (A_2 - A_1)},
\]

where all other variables and parameters defined as before.

The introduction of the two variables, S and RNTB, had the potential to alter the solution of equations (2) if they were not constant terms; i.e., if S and/or RNTB were functions of plantation age, then the solutions in equations (4) do not follow from the differential equations. The following hypotheses were tested via simple linear regression to determine if S and RNTB were constant terms before the equations (4) were fit to the data:

- Ho1: S is constant across plantation age,
- Ho2: RNTB is constant across plantation age, and
- Ho3: S*RNTB is constant across plantation age.

None of the three hypotheses were rejected at the \(\alpha = 0.01\) probability level \(P = 0.6393, P = 0.0117, P = 0.0706, \) respectively), so S and RNTB were assumed to be constant across the range of plantation ages in this study.
After S and RNTB were found to be constants, equations (4) were fit to the data. Preliminary analyses (not presented) showed that survival, site index, and RNTB were significantly correlated ($P < 0.05$). A fitting procedure described by Borders (1989) was used to account for the presence of this cross-equation error correlation. As a result, equations (4) were fit to the 197 observations in a simultaneous manner using the SYSNLIN procedure in SAS (1985).

**Model evaluation.**—The statistical measures used in this study for model evaluation were the coefficient of determination ($R^2$), root mean square error (RMSE), mean percent bias (described below), and a simple linear regression analysis of observed versus predicted total surviving trees per hectare (described next).

Simple linear regression (Zar 1999) was used to compare observed and predicted total surviving trees per hectare. Observed and predicted values were related according to the following simple linear model: Predicted TPH = $b_0 + b_1 \times$ Observed TPH. If the survival prediction models correctly estimated the number of surviving trees per hectare, then the intercept ($b_0$) would not be significantly different from zero and the slope ($b_1$) would be not be significantly different from one. A simultaneous $t$-test (Neter et al. 1985: p. 147) was used to evaluate the hypothesis: $H_0: (\beta_0, \beta_1) = (0,1)$, $H_a: (\beta_0, \beta_1) \neq (0,1)$.

Reynolds (1984) developed estimation procedures to test the accuracy of models. His procedures test both bias and precision rather than overall prediction accuracy. These procedures were converted to a BASIC program (Rauscher 1986), then later to a SAS program (SASATEST; Gribko & Wiant 1992). SASATEST was used in this study to further examine the performance of the survival prediction models. SASATEST examines both bias and precision on an absolute or percentage basis. In SASATEST, percent bias is calculated as a percentage of the observed surviving trees per hectare:

$$BIAS = 100 \frac{\hat{Y} - Y}{Y},$$

where:

$\hat{Y} =$ predicted surviving trees per hectare and $Y =$ observed surviving trees per hectare. In this study, precision is expressed as the standard
deviation of percent bias, which is also calculated by SASATEST. SASATEST then uses the mean percent bias (measure of bias) and the standard deviation (measure of precision) to calculate a 95% confidence interval. If this confidence interval does not contain zero, then the bias is significant at the $\alpha = 0.05$ level. SASATEST also checks the errors between predicted and observed values for departures from normality. If non-normality is detected, a 10% trimmed mean and jackknife standard deviation were used to provide more robust confidence intervals.

**RESULTS AND DISCUSSION**

**Survival prediction models.**—The following model developed from the slash pine plantation survival data provides separate estimates of the surviving number of slash pine trees:

\[
N_{u2} = (N_{il} - 0.424429N_{u1})e^{(-0.021002(S*RNTB)(A_2 - A_i))} + 0.424429N_{u1}e^{(-0.00541647(S*RNTB)(A_2 - A_i))}
\]

\[
N_{u2} = N_{u1}e^{(-0.00541647(S*RNTB)(A_2 - A_i))},
\]

where, all variables are defined as before.

The asymptotic standard errors for coefficients $\hat{\rho}_1$, $\hat{\alpha}$, $\hat{\beta}$ are 0.0030458, 0.0012421 and 0.12514, respectively. All parameters were significantly different from zero ($P < 0.05$). The uninfected component in equation (5) explained about 92% of the variation in the surviving number of trees per hectare, while the infected component in equation (5) explained about 56% of the variation in the surviving number of trees per hectare (Table 2). Thus, the uninfected component was more accurately predicted than the number of surviving infected trees. Residual plots (not shown) revealed a random pattern around zero with no detectable trends. Fit statistics for equation (5) based on the data from 194 evaluation subplots are presented in Table 2.

The survival prediction model (5) for uninfected slash pine trees over-estimated the number of surviving trees per hectare by 2.42%, though this value was not significant ($P > 0.05$; Table 2). The survival prediction model (5) for infected slash pine trees significantly ($P < 0.05$) over-estimated the number of surviving trees per hectare by 7.46% (Table 2). This large value can be explained by the large amount of variability in the percent bias values (note the large confidence interval...
Table 2. Fit statistics for performance evaluation of east Texas unthinned slash pine plantation survival model. \( N_{u2} \) = number of surviving trees per hectare without a fusiform rust stem gall at Age 2, \( N_{i2} \) = number of surviving trees per hectare with a fusiform rust stem gall at Age 2, and ** = significant (\( P < 0.05 \)).

<table>
<thead>
<tr>
<th>Equation</th>
<th>( R^2 )</th>
<th>Root Mean Square Error</th>
<th>Mean Percent Bias</th>
<th>95% Confidence Interval for Percent Bias</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_{u2} )</td>
<td>0.92</td>
<td>100.82</td>
<td>2.42</td>
<td>2.42 ± 3.12</td>
</tr>
<tr>
<td>( N_{i2} )</td>
<td>0.56</td>
<td>106.23</td>
<td>7.46**</td>
<td>7.46 ± 5.59</td>
</tr>
</tbody>
</table>

in Table 2). This result was not unexpected since less variability in the predicted number of surviving trees was explained by the model for infected trees (\( R^2 = 56\% \); Table 2) versus uninfected trees (\( R^2 = 92\% \); Table 2). Adams (1989) and Adams et al. (1996) also found a larger variability in predicting infected fusiform rust incidence versus an uninfected incidence.

The survival prediction equations (5) significantly (\( P < 0.05 \)) over-estimated the total number of surviving trees by 3.25\% (95\% confidence interval for overall model bias = 3.25\% (1.19\%)) across the range of observed stand densities. The simultaneous \( f \)-test also revealed that the total estimated number of surviving trees per hectare was significantly different (\( P < 0.0001 \); \( f \)-statistic = 33) from the total observed number of surviving trees per hectare (Figure 1). The total number of surviving trees per hectare is over-estimated to a greater magnitude for densities > 1000 trees per hectare than at densities < 1000 trees per hectare (Figure 1). This result is not unexpected considering that fewer, high-density plots were available for model fitting. However, this bias is not a practical concern because tree densities in operational east Texas slash pine plantations typically do not exceed 1000 trees per hectare.

In this study, the null hypothesis, \( H_0 \): \( RNTB \) is constant across plantation age, would have been rejected at the \( \alpha = 0.05 \) probability level (\( P = 0.0117 \)). This implies that \( RNTB \) is not strongly disassociated from plantation age, which may be a problem because the solution to the differential equation does not follow as stated in this study if \( RNTB \) is a function of age (note that \( S \cdot RNTB \) was used in [5], and it was not significantly [\( P = 0.0706 \)] associated with age). We did not find a similar result when this survival model was fit to data for loblolly pine plantations in east Texas (Lee & Coble 2002). No clear explanation can be provided as to the different results. One possible explanation could be that slash pine was more likely to become infected and die.
than loblolly pine. So, more growing space might have been available to the non-planted trees as the plantation aged, thereby increasing RNTB as time increased. Another possible explanation could be that a larger dataset was available to fit the loblolly survival equations, thereby better capturing the effects of non-planted tree competition on planted pine survival. In any case, a survival model that incorporates non-planted tree competition as a function of age would be ideal.

**Illustrations of Survival Projections**

The predicted numbers of surviving slash pine trees (both infected and uninfected) decreases as the percent of non-planted tree basal area increases (Figure 2). In Figure 2, the percent of non-planted tree basal area to total basal area per hectare ranges from 10% to 60%, site index = 21 meters, and stem fusiform rust incidence at year 5 = 10%.

The total number of survivors can also be divided into the number of slash pine trees infected or uninfected by fusiform rust (Figure 3). In Figure 3, the numbers of uninfected and infected slash pine trees are displayed for the 15% of non-planted tree basal area to total basal area per hectare (RNTB = 0.15), site index = 21 meters, and stem fusiform rust incidence at year 5 = 10%.

The predicted numbers of surviving slash pine trees (both infected and uninfected) also decrease as site index increases (Figure 4). In Figure 4, site index ranges from 15 to 30 meters, the ratio of non-planted tree...
Figure 2. Predicted surviving planted slash pine trees by plantation age and the percent of non-planted tree basal area to total basal area per hectare classes. Site index = 21 meters (base age = 25 years); stem fusiform rust incidence = 10% at 5 years.

Figure 3. Numbers of surviving slash pine trees infected and not infected by fusiform rust by plantation age. The ratio of non-planted tree basal area to total basal area per hectare = 15%; site index = 21 meters (base age = 25 years); stem fusiform rust incidence = 10% at 5 years.

basal area to total basal area per hectare was 15% (RNTB = 0.15), and stem fusiform rust incidence at year 5 was 10%. These results corroborate those of Adams (1989) and Adams et al. (1996). As explained
earlier, mortality occurs at a faster rate on more productive sites. Thus, more productive sites have fewer trees at a given age than less productive sites.

**Conclusions**

The results of this study show that the number of surviving slash pine trees both infected and uninfected by fusiform rust can be accurately predicted for a range of site qualities and levels of non-planted tree competition. The survival model (equation 5) depicts the decreasing number of surviving slash pine as non-planted tree competition and fusiform rust incidence increases. Though the model significantly over-estimates the total number of surviving trees at densities >1000 trees per hectare, this is of no practical concern since operational slash plantations in east Texas typically do not exceed 1000 trees per hectare. Management activities that reduce the number of non-planted trees early in the life of the plantation are beneficial to increasing the survival of the planted slash pine trees. This reduction is also an important consideration on the sites with higher productivity since the total number of surviving trees decreases as site index increases.
ACKNOWLEDGEMENTS

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LITERATURE CITED


Haywood, J. D. & A. E. Tiarks. 1990. Eleventh year results of fertilization, herbaceous,

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Abstract.—This study documents the mass capture by Sarracenia alata (pitcher plant) of Plecia nearctica (lovebug) during an emergence that occurred in southwest Louisiana and southeast Texas during the fall of 1996. An estimated 7700 pitcher plants in a 0.4 ha bog area were found to be capable of harvesting approximately two million specimens of P. nearctica. Several proposals relative to the understanding of mass insect captures by pitcher plants are also discussed.

Published observations on mass capture of insects by carnivorous plants are rare. Oliver’s (1944) account of a 1911 emergence of cabbage white butterflies (Pieris rapae), in which six million butterflies were caught on a two acre patch of sundews (Drosera anglica Huds.) in only nine hours, is a spectacular example of the episodic nature of insect capture by a carnivorous plant species. Although Juniper et al. (1989) comment that all carnivorous plants, particularly those living near patches of open water or on the migration routes of insects, are likely to experience episodic arrivals of one or a few species, documented observations of carnivorous plant and episodic insect interactions are rare; indeed, studies of insect capture processes in carnivorous plants are rare.

Studies of normal capture and feeding rates for carnivorous species show wide variations. Some species appear to capture very little, which, along with laboratory experiments where carnivorous species are grown without supplemental food, suggests that insects may not be required for carnivorous plant growth and reproduction (Adamec 1997). For example, Newell & Nastase (1998) found that New Jersey populations of Sarracenia purpurea L. captured 2.1% of potential prey,
resulting in only about one insect every 15 days. Heard (1998) found that *S. purpurea* in Newfoundland captured a paltry 11 mg (range 0-67 mg) dry mass over its lifetime. In another study, Dixon et al. (1980) found that *Drosera erythrorhiza* Lindl. in Australia averaged only 2.5 organisms per plant in one year and 6.9 in another. However, others have found much higher capture rates and have found that captured insects contribute significantly to growth and reproduction (Gibson 1991; Adamec 1997). Gibson (1983:105, Appendix 3), for example, reported much higher capture rates for such carnivorous plants as *Sarracenia leucophylla* Raf. and *Drosera* in the southeastern United States. He found up to ten prey captured per day and in *S. leucophylla* about 0.50 g dry insect biomass per trap during a season. Folkerts (1992) found the mean dry weight of arthropod prey captured in *Sarracenia alata* Wood study plots was between 5 and 60 mg; she also briefly mentioned Bibionid (Diptera: Bibionidae) outbreaks but that rarely were pitchers filled to capacity. On the other hand, Folkerts & Folkerts (1995:7) stated in a brief description of *S. leucophylla*: "When plagues of lovebugs ... occur, the pitchers fill to the brim, some containing more than 2,000 love bugs." The overall conclusion is that, while carnivorous species lie along a gradient from near independence to almost total dependence on prey for their growth, for reproduction and spread in natural habitats, as opposed to greenhouse settings, prey are necessary (Givnish 1989; Juniper et al. 1989; Adamec 1997).

Each September, mating flights of lovebugs (Diptera: *Plecia nearctica* Hardy) occur throughout the southeast (Hetrick 1970; Denmark & Mead 1992). These flights begin with swarms of males and eventually consist largely of copulating pairs; the females are gravid (Hetrick 1970; Denmark & Mead 1992). The intensity of flights varies annually, with an occasional emergence (large magnitude flights) taking place. Emergences are spectacular events of short duration, which attract much local attention; many thousands of individuals may be smashed by vehicles traveling only a few miles.

Between 1991 and 1998 two large emergences were observed and prompted these observations made in September 1996 on mass capture in *S. alata* in southeastern Texas and southwestern Louisiana where pitcher plants are common (MacRoberts & MacRoberts 2001).
Study Sites

Observations were made on rate of capture and distribution of the phenomenon in two pitcher plant bogs on the Angelina National Forest, Angelina and Jasper counties, Texas, and in one bog on the Vernon Ranger District of the Kisatchie National Forest in Vernon Parish, Louisiana. General observations on the emergence of lovebugs were made across southeast Texas and southwest Louisiana.

Materials and Methods

Late summer pitchers over 20 cm tall were counted in a 0.4 ha hillside bog in east Texas. The bog had approximately 7700 pitchers all of which were full of insects. In addition, the insect contents of 35 pitchers were extracted and counted, and from these data lovebug capture rates were extrapolated. A sample of 1000 lovebugs was collected, which had a dry weight of 2.4 g. Since lovebugs are potentially important sources of minerals, including several that have been considered limiting in carnivorous plant habitats (Gibson 1983), lovebugs and pitcher plant leaves were chemically analyzed by A & L Laboratories, Memphis, Tennessee.

Results

Plants of *Sarracenia alata* in hillside bog communities produce new traps in both the spring and late summer (MacRoberts & MacRoberts 2001). In September 1996, new summer pitchers quickly filled with lovebugs; whereas old spring pitchers remained empty. In each of several bogs examined during this period, all new pitchers over approximately 20 cm in height were filled almost to the pitcher opening. Approximately 2 to 4 cm of the uppermost lovebugs were alive; most were trapped, except those on the upper surface layer that were able to crawl freely in and out of the pitchers. Slightly farther down the pitcher, lovebugs were dead, in various stages of digestion and decomposition.

For the 35 pitchers examined for insect contents, with the exception of an occasional moth, pitchers were invariably filled with lovebugs (Fig. 1). The largest pitchers, measuring up to 70 cm in height with 5
Figure 1. Number of lovebugs caught as a function of pitcher plant height.

cm diameter openings, had captured almost 600 lovebugs. Smaller pitchers (20 cm or less) trapped primarily ants, but these were not filled; only one of 12 pitchers in this size class had captured lovebugs.

At observed capture rates of approximately 250 lovebugs/pitcher, this bog was harvesting approximately two million lovebugs. The largest pitchers in our sample were capturing approximately 1.4 g (dry weight) of lovebugs in a short period, and the bog community was capturing between 4 and 5 kg of material (dry weight). Chemical analysis of lovebugs and pitcher plant leaves is shown in Table 1.

Although gorging appears to provide access to significant nutrient supplies, mass capture of this magnitude may have some drawbacks. Filled pitchers showed signs of rotting. In a sample of 23 filled pitcher plants over 20 cm tall, leaf tissue on 21 was rotting. Rot generally
Table 1. Element composition in lovebugs and plant leaf.

<table>
<thead>
<tr>
<th>Element</th>
<th>Lovebugs</th>
<th>Plant leaf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>13.04%</td>
<td>2.24%</td>
</tr>
<tr>
<td>Sulphur</td>
<td>0.94%</td>
<td>0.16%</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>1.20%</td>
<td>0.24%</td>
</tr>
<tr>
<td>Potassium</td>
<td>1.36%</td>
<td>0.60%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.22%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Calcium</td>
<td>0.31%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Sodium</td>
<td>0.24%</td>
<td>0.10%</td>
</tr>
<tr>
<td>Boron</td>
<td>8 ppm</td>
<td>7 ppm</td>
</tr>
<tr>
<td>Zinc</td>
<td>293 ppm</td>
<td>29 ppm</td>
</tr>
<tr>
<td>Manganese</td>
<td>28 ppm</td>
<td>19 ppm</td>
</tr>
<tr>
<td>Iron</td>
<td>263 ppm</td>
<td>70 ppm</td>
</tr>
<tr>
<td>Copper</td>
<td>31 ppm</td>
<td>10 ppm</td>
</tr>
<tr>
<td>Aluminum</td>
<td>115 ppm</td>
<td>43 ppm</td>
</tr>
</tbody>
</table>

began opposite the ala of the pitcher between 60 and 90 percent of the pitcher height (Figure 2). Neither small pitchers (lacking lovebugs) nor spring pitchers appeared to have rotted at all, and fall pitchers in non-emergent years do not show rot. Similar observations of rotting due to gorging have been made for S. leucophylla by the third author (T.C.G.) in Florida on plants filled with lovebugs. As a result of gorging and then rotting, the plant may be losing photosynthetic ability because of tissue loss.

**Discussion**

It has been hypothesized that insect resources are particularly important because they allow plants to accumulate nutrient reserves that permit greater flowering, increased seed production, and recovery from disturbance (Gibson 1983; 1991). If it is assumed that normal feeding provides these reserves, as most studies of carnivory suggest, and the chemical analysis presented here suggests, then episodic capture may provide an additional accumulation.
Emergences such as those described here far exceed normal insect numbers, and consequently it is likely that pitchers would catch more of these species than other less common insects. The question is: Are the emergences of lovebugs a repeating cycle to which pitcher plants have adapted?

On the other hand, it is also possible that since lovebugs are an expanding species that has only recently been noted to have massive emergences (Hetrick 1970; Denmark & Mead 1992), they may be co-evolutionarily naive to pitcher plants; hence, there has not yet been selection for avoidance of the traps. In support of this hypothesis, the third author (T.C.G.) has found that fire ants, new to Florida, sometimes get trapped in large numbers. However, it is also possible that lovebugs have pheromones that attract other lovebugs and that once a few are trapped in a pitcher, more and more become attracted to it by
the sexual odor. Capture may, therefore, have nothing to do with naivete.

Although this type of episodic capture has been witnessed in many places, it is very poorly reported. The present findings supplement those of Juniper et al. (1989) by expanding the range of episodic interactions; the present observations were not of migratory insect flights and the sites were not adjacent to open water. Clearly, further observations, even anecdotal ones, would be welcome. Detailed study of such events, however, may be hampered by their unpredictability, infrequency and short duration.

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LITERATURE CITED


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FEMALE REPRODUCTION IN THE WESTERN DIAMOND-BACKED RATTLESNAKE, *CROTALUS ATROX* (SERPENTES: VIPERIDAE), FROM ARIZONA

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Abstract.—Reproductive tissue was examined from 46 sexually mature female *Crotalus atrox* specimens from Arizona, and additional data were obtained from gravid females held in the laboratory and from palpation of live snakes in the field. Mean litter size for 19 females was $8.3 \pm 2.6$ SD range = 5-15 based on enlarged (> 12 mm) ovarian follicles, but was significantly less in 10 records of oviductal ova or whole litters, at $5.6 \pm 1.5$ SD, range = 4-9, with an overall mean of $7.3 \pm 2.6$ for adult females averaging 797 mm SVL, range = 648-1010. These values are lower than estimates in the literature from elsewhere, but seem consistent with the smaller observed size of adult females in the desert region where the samples originated. The number of enlarged follicles correlated positively with female SVL, but oviductal eggs and neonates did not. Four values for RCM ([clutch mass] / [gravid female mass]) averaged $0.303 \pm 0.099$ SD, range = 0.222 - 0.438. Twenty-one neonates born to wild-caught females averaged 319.7 mm total length and 19.6 g body mass. Enlarged ovarian follicles (> 12 mm length) were found February-June (ovulation during present year) and September-November (ovulation next year), and young are born in late July to September. The earliest field dates for appearance of neonates ($n = 75$ observed) were 8-11 August. Yolk deposition is normally completed over two activity seasons, although there was some indication that during times of great abundance for rodent prey, individual females might reproduce in successive years. On average, approximately half of all females reproduce in a given year, but significantly higher proportions (73%) were gravid in years of higher compared to lower rodent abundance (28% gravid).

The western diamond-backed rattlesnake, *Crotalus atrox*, ranges from southeast California to Arkansas and eastern Texas, Arizona, New Mexico and Oklahoma, south to northern Sinaloa and San Luis Potosí, Mexico (Stebbins 1985). There is little information available on the seasonal ovarian cycle of this species. Reports on female *C. atrox* reproduction are in Tinkle (1962), Klauber (1972), Tennant (1984), Fitch (1985), Lowe et al. (1986), Ernst (1992), Fitch & Pisani (1993), Price (1998) and Werler & Dixon (2000). The purpose of this paper is to provide information on the ovarian cycle of *C. atrox* from Arizona and to present the first seasonal reproductive data for females of this species. These data will be useful for making comparisons of the reproductive output of Arizona *C. atrox* with populations elsewhere in
its geographic range.

**Materials and Methods**

Forty-three female *C. atrox* from Arizona were examined from the herpetology collection of the University of Arizona, Tucson (UAZ) and three additional dissections were performed in the field (*n* = 46, mean Snout-Vent Length, SVL = 792 mm ± 86 SD, range = 636-1010 mm). Snakes were collected 1949 to 1998. The left ovary was removed for histological examination. Histological sections of ovary were examined for the presence of yolk deposition (secondary vitellogenesis *sensu* Aldridge (1979). No histology was done on enlarged follicles (> 12 mm length) or oviductal eggs, both of which were counted. In addition, in the course of field studies, five adult females found gravid in the field during July-August were held until parturition, and weights and lengths of the neonates were recorded prior to their release at study areas. During field work between Tucson and Organ Pipe Cactus National Monument (ORPI), Pima County, 59 adult females were palpated during May-July, when reproductive status (gravid versus non-gravid) for the year could be determined, and counts of ovarian or oviductal ova were made on five of these. The relationship between SVL and litter size was investigated by regression analysis. *T* tests were used to compare mean litter sizes, and a corrected chi-square test to compare gravid functions among yearly samples.

*Material examined.—*The following specimens of Arizona *C. atrox* females were examined: MARICOPA COUNTY, 2 specimens (UAZ 46426, 50737); MOHAVE COUNTY, 2 specimens (UAZ 27112, 37052); PIMA COUNTY, 31 specimens (UAZ 13556, 13564, 13565, 27093, 27102, 27120, 27165, 27170, 27172, 27179, 27180, 27209, 27218, 27238, 27293, 27294, 27298, 27318, 27320, 27323, 27333, 42486, 44076, 44939, 46412, 47966, 48853, 48854, 51488, 54048, 54049); PINAL COUNTY, 5 specimens (UAZ 27094, 27162, 27291, 27732, 27334); SANTA CRUZ COUNTY, 1 specimen (UAZ 27121); YUMA COUNTY, 2 specimens (UAZ 27215, 35868).

**Results and Discussion**

Females with enlarged follicles (> 12 mm length) or oviductal eggs were found February-June and September-November (Table 1). Those females from February-June would likely have ovulated and produced
Table 1. Monthly distribution of conditions in seasonal ovarian cycle of 46 *Crotalus atrox*. Values shown are the number of females exhibiting each of the four conditions.

<table>
<thead>
<tr>
<th>Month</th>
<th>n</th>
<th>Inactive</th>
<th>Early yolk deposition</th>
<th>Enlarged follicles &gt; 12 mm length</th>
<th>Oviductal eggs</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>March</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>7</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>May</td>
<td>11</td>
<td>3</td>
<td>0</td>
<td>7(^a)</td>
<td>1</td>
</tr>
<tr>
<td>June</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>July</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>August</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>September</td>
<td>6</td>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>October</td>
<td>4</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>November</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

\(^a\) Includes one female with enlarged squashed follicles that could not be counted.

young later that year. The eggs in the only oviductal female (UAZ 27170) found in a museum collection specimen, collected 21 May were squashed making it impossible to count them. The females with enlarged eggs from September-November would likely have ovulated the next spring and given birth later that summer indicating that yolk deposition is completed over two activity seasons. This also occurs in other North American rattlesnakes (Goldberg 1999a; 1999b; 1999c; 2000a).

The smallest reproductively active female (UAZ 27320) (enlarged follicles > 12 mm) measured 648 mm SVL, and the mean size of gravid females in Table 2 was 797 ± 75 mm SVL. The mean litter size based on ovarian follicles (> 12 mm) for 19 *C. atrox* females from Arizona was 8.3 ± 2.6 SD, range = 5-15. This value may be higher than what actually occurs since not all enlarged follicles may complete development. Indeed, mean litter size in 10 females based on oviductal eggs or young born was significantly lower (\(t = 3.36, df = 24, P < 0.01\)), at a mean of 5.6 ± 1.5 SD, range = 4-9. Overall mean litter size was 7.3 ± 2.6 for adult females averaging 797 mm SVL, range = 648-1010 mm. Relative clutch mass (RCM) for four litters averaged
Table 2. Litter sizes for 29 *Crotalus atrox* females from Arizona. All museum specimens represent counts of enlarged follicles > 12 mm length in dissected snakes. Snakes that were palpated or gave birth in captivity were released as part of a marking study. Those held for live-bearing were captured in July or August.

<table>
<thead>
<tr>
<th>Date</th>
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a  Produced infertile eggs, 3 August 1989
b  Postpartum; 4 large corpora lutea and vascularized oviductal sites

0.303 ± 0.099 SD, range = 0.222 – 0.438 based upon (offspring mass)/(gravid female mass), and was 0.484 ± 0.167 SD, range = 0.370 – 0.637 based upon (offspring mass)/(postpartum female mass). These values are close to the mean value for other viviparous snakes, including vipers, given by Seigel & Fitch (1984).

The litter size value based on enlarged ovarian follicles is within the range, but slightly lower than in other reports: 6-19 in Tinkle (1962), 2-24 in Lowe et al (1986), 6-25 in Armstrong & Murphy (1979), 4-24 in Fitch & Pisani (1993), and 4-24 in Klauber (1972) for C. atrox. Estimates of litter size in this study were significantly lower than that based on Klauber’s (1972) data (10.2 ± 5.3, n = 36), whether based on ovarian follicle results (t = 1.78, df = 53, P < 0.05) or on all data (t = 2.78, df = 63, P < 0.004). Klauber’s (1972) sample may have been heterogeneous, and Fitch & Pisani’s (1993) estimate based on enlarged ovarian follicles from an Oklahoma sample was even higher at 13 ± 4.4. The mean size of reproductive females in the current study (797 mm SVL) is lower than the minimum SVL for maturity of about 830 mm in Fitch & Pisani (1993) and 800 mm in Tinkle (1962), although Klauber (1937) reported a considerably lower minimum size of 742 mm (apparently total length) for gravid female C. atrox. However, this estimated litter size is more or less consistent based on extrapolation to the smaller size, with the size-fecundity graph for Oklahoma (Fig. 6 in Fitch & Pisani 1993).

It is possible that during this C. atrox study in the Sonoran Desert, Pima County, realized litter size was lower than potential litter size that would be inferred based on enlarging ovarian follicles. Female C. atrox
at ORPI at times appeared highly stressed (underweight, weak and not robust), particularly when reproduction coincided with drought. Among the captive females, one litter of five consisted of undeveloped eggs, and 1 of 21 other births was a partially developed embryo with yolk attached.

Births were recorded in the laboratory on 3 August (infertile eggs), and 27 August, 28 August, 14 September and 29 September. Captivity may have delayed birth somewhat. Recently postpartum females were found at ORPI on 12 August-18 September, and the latest capture of a gravid female was 24 August. Copulation was observed in the field on 25 August 2001 at the old Esmond Railroad Station near Tucson and at a den a few miles east of there on 12 March 1997. Neonates born to wild-caught females \((n = 21; 10 \text{ males}, 11 \text{ females})\) averaged 319.7 ± 14.8 SD mm total length, range = 294–345, and 19.55 ± 2.81 SD g total body mass, range 16.9–24.7. Neonate males and females were closely similar in mass and total length, although in females the tail was shorter (7.6 % of SVL) than in males (10.8 % of SVL). The earliest appearances of neonates in the field \((n = 75 \text{ observed})\) were 8 August in the grassland of southeastern Arizona, 10 August near Tucson and 11 August at ORPI; there is some indication that birth, or at least the appearance of young, is later at ORPI than in southeastern Arizona (Fig 1). Since neonatal rattlesnakes, including \(C. atrox\) appear to remain aggregated and with their mother for about 10 days (see Price 1988), their detection in the field portrayed in Fig. 1 is probably delayed relative to birth. Thus, these results generally support a late July to early or mid-September parturition period for \(C. atrox\) in southern Arizona.

Regression analysis revealed a significant positive correlation between \(\ln (\text{Litter Size})\) and \(\ln (\text{SVL})\) for 28 litters of \(C. atrox\) in Table 2: \(\ln (\text{Litter Size}) = -6.41 + 1.25 \ln (\text{SVL}); r^2 = 0.12; P = 0.05.\) Back transformed this regression equation describes the allometric relationship between the variables via a power function: \(\text{Litter Size} = e^{-6.41} \text{SVL}^{1.25}.\) However, the entire positive relationship was based on counts of enlarged ovarian follicles; no relationship was found between female SVL and litter size based on embryos or live-born litters (Fig. 2).

The presence of inactive females, comprising nearly half (48%) of the dissection sample, shows that not all females reproduce each year. This
Figure 1. Seasonal distribution of observed young of the year with a single rattle segment (YoY) for *Crotalus atrox* in southern Arizona, 1985 – 2001. Field work was carried out throughout March to early November at or near Organ Pipe Cactus National Monument in western Pima County and near Tucson, primarily in Arizona Upland Sonoran desert scrub, and in the desert grassland of Sulphur Springs, San Bernardino, and Altar valleys of southeastern Arizona. By mid-October, most YoY had 2 or 3 rattle segments, and were not included in this histogram.

is also born out in the palpation results (Table 3), in which 51% of the sample was found to be non-gravid during the gravid season. Biennial, triennial or less frequent reproduction appears to be common among species of North American rattlesnakes (Goldberg 1999a; 1999b; 2000b; Goldberg & Holycross 1999; Holycross & Goldberg 2001). Tinkle (1962) reported female *C. atrox* from Texas to reproduce biennially, although Fitch & Pisani (1993) found *C. atrox* from Oklahoma to reproduce annually. Werler & Dixon (2000) reported that *C. atrox* from northern Texas where the winters are severe reproduce biannually, whereas those living in the warmer southern part of the state reproduce annually. Goldberg & Rosen (2000) reported that yearly percentages of gravid *Crotalus scutulatus* appeared related to food abundance. This trend, first reported for *C. scutulatus*, was also found to be highly significant for *C. atrox* in southern Arizona. In years in which rodent monitoring indicated low food availability for the snakes (1989-90,
Figure 2. Linear regressions of number of enlarged ovarian follicles (> 12 mm length), and of oviductal eggs and neonates born, on snout-vent length (mm) of the mother for 28 *Crotalus atrox* females from Arizona. Open circles represent enlarged ovarian follicles; solid circles represent oviductal eggs or neonates.

1996-98), the gravid fraction (28%) was significantly lower than in years of "booming" rodent populations (1991-1995; 73%; corrected chi-square = 8.64, df = 1, P < 0.005). The run of years with high clutch frequency (Table 3) suggests that female *C. atrox* may sometimes reproduce in successive years in the Sonoran Desert. This hypothesis remains to be demonstrated rigorously, but is consistent with geographic variation in reproductive frequency found in the literature cited above.

Fitch (1985) suggested litter sizes of *C. atrox* increased southward and decreased westward. Results of this current study support decreased litter size in the west, and suggest that various stresses associated with the increasingly arid environment may be contributory. Examinations of *C. atrox* females from various parts of its range will be required before the degree of variation in the ovarian cycle of this wide-ranging species can be known in detail. While some information on female reproduction can be obtained from examination of museum specimens, additional field studies will be essential to ascertain the frequency of female *C. atrox* reproduction.

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ACKNOWLEDGMENTS

We thank Charles H. Lowe (University of Arizona) for permission to examine *C. atrox* and George L. Bradley, Peter A. Holm, David A. Parizek Jr., Shawn S. Sartorius, Elizabeth B. Wirt and many others for important field and laboratory assistance.

LITERATURE CITED


PCR at: pcrosen@u.arizona.edu
NEW DISTRIBUTION RECORD AND ECOLOGICAL NOTES OF THE FRESHWATER HYDROZOA CRASPEDACUSTA SOWERBII IN SOUTHEAST TEXAS

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Department of Biology, Lamar University
Beaumont, Texas 77710

Abstract.—Crasedacusta sowerbii, the only species of freshwater cnidarian exhibiting a medusa stage in its life cycle, was collected from an excavated pond in Jefferson County, Texas from 6 July to 12 November 2001. Density was patchy and mean density per collection date varied from 0.59/m³ to 34.43/m³. The highest density from a single plankton tow was 121.32/m³. Five polyps were collected from artificial substrates suspended in the water column, indicating that sexual reproduction had occurred. The medusae disappeared when the temperature decreased to 21°C even though the zooplankton food supply was still abundant.

Crasedacusta sowerbii Lankester (Cnidaria: Hydrozoa) is the only species of freshwater cnidarian in North America exhibiting a medusa stage in its life cycle. It has been reported from at least 40 states and over 100 locations (Acker & Muscat 1976; Devries 1992; http://www.iup.edu/~tpeard/jellyfish.html ). However, its occurrence is sporadic and each new sighting is considered noteworthy. Previously published Texas records of C. sowerbii were by Cheatum (1934), Schmitt (1939), Jurgens (1957), all from central Texas, and Baker (1960) and McCullough et al. (1981) from east Texas.

During July of 2001 a population of C. sowerbii was discovered in Kaiser Pond located in northwest Beaumont, Jefferson County, Texas. It is located about 200 m south of Spurlock Road between Major Drive and Keith Road at latitude 30° 08.34' north, longitude 90° 12.37' west. This report documents ecological observations of this population and limnological conditions in Kaiser Pond from 6 July to 12 November 2001 when medusae were present.

DESCRIPTION OF THE POND

Kaiser Pond basin was constructed in 1985 by excavation of Beaumont clay soil. The pond is 48.5 m wide and 88 m long with a surface area of 0.43 ha (1.2 acres). The margins have a steep slope and most of the pond is about 4 m deep. However, a 7 to 8 m deep trench is located at the south end of the pond. The water level was fairly constant and never varied more than 0.7 m. Two piers extend out into
the pond. The west pier is 10 m long and the east pier is about 25 m long and was used to collect physical/chemical data and to take plankton tows. The pond receives very little surface runoff due to elevated surface soil deposited during construction surrounding the pond. About 44 m of the east bank has a concrete apron that extends out into the water about 5 or 6 m to a depth of about 2 m. No aquatic vascular plants were present and filamentous algae were absent in the water column, but *Oscillatoria* coated the concrete apron and the pilings of the piers. The pond has a large fish community that was stocked from various sources. This stocking appears to be the probable means by which *C. sowerbii* was introduced into the pond. The pond was built for recreation purposes and is frequently visited by the owner throughout the year. This was the first year that the medusae were observed.

**Materials and Methods**

Visual observations and measurements of physical/chemical conditions and/or medusa densities were taken on 27 different dates from 6 July to 19 December 2001. Observations of medusae were taken from both piers on each date and while snorkeling on 12 July, 2 August, 4 August and 7 September. Density of the medusae was determined by towing a No. 20 plankton net, with a 30 cm opening, 10 to 20 m from a depth of about two meters to the surface from the east pier. Some of the water from the plankton net bucket was preserved and used to determine the types of plankton present.

Physical/chemical measurements were taken from the end of the east pier where the water depth varied from 3.3 to 4 m. Water temperature, dissolved oxygen concentration, oxygen percent saturation, pH and specific conductivity were measured at meter depth intervals using a Hydrolab Surveyor 3 and H2O Multiprobe. Water depth was determined using the Hydrolab and a hand held Speedtech Depthmate portable sounder. Alkalinity was determined by titration (APHA 1989). Water transparency was determined with a Secchi disk and euphotic depth with a submarine photometer. Artificial substrates of the Parsons & Tatum (1974) design (0.09 m$^2$ surface area) were suspended at depths of 0.5, 1.0 and 1.5 meters and removed after seven weeks and 12 weeks in an attempt to collect the polyp life cycle stage.

**Results and Discussion**

Kaiser Pond exhibited no thermal stratification and the maximum difference between the surface and the 4 m depth was 2°C. Water
temperature ranged from 33 to 21°C when the medusae were present (Table 1). Dissolved oxygen concentrations varied from 9.4 mg/L (133 % saturation) at 3 m to 0.2 mg/L (3.3 % saturation) at 3.8 m. During most collections oxygen concentrations were similar and > 60% saturation at all depths, except at the bottom. The pH ranged from 6.5 to 7.8 and all values <7.0 occurred directly after heavy rains. Surface alkalinity ranged from 109 to 115 mg/L. Specific conductance ranged from 249 to 269 μS/cm. The Secchi disk depth varied from 1.8 to 3.8 m. The wide variability was due to time of day, cloud cover and surface water movements when the measurements were taken. The euphotic depth varied from 3.3 to >4 m. The pH, alkalinity, specific conductance and water transparency were all higher than most local surface waters. Other ponds in this area constructed on Beaumont clay are always very turbid due to colloidal clay particles. All water quality parameters were within the ranges where C. sowerbii had been reported by other investigators.

The medusae were first observed by the pond’s owner during early June 2001. The density was already very high at this time; the owner collected five specimens by dipping a narrow mouth bottle (≈ 500 mL) into the water. These were taken to the county extension agent for identification. They were then brought to this investigator. The first observation by the author was on 6 July 2001 and about 50 specimens were collected off the west pier with five or six sweeps of a dip net. These specimens were maintained in the laboratory in aerated pond water until 2 August, when the last specimen died. When collected they varied from 15 to 22 mm in diameter. The longer they were held in the laboratory the smaller they became and were between 5 and 10 mm in diameter when they died. Other attempts to maintain the medusae in the laboratory had similar results.

Qualitative observations of the medusae were made on 22 dates between 6 July and 7 November, and by snorkeling on 12 July, 2 August, 4 August and 7 September. Medusae were observed throughout the pond, however none were ever observed closer than about five meters from the shore. While swimming, their tentacles were extended aborally in the direction of movement. Many specimens would swim up in the water column until the longer tentacles touched the surface, they would then flip over and swim sideways or down. While snorkeling, many specimens brushed against the swimmers exposed skin and only a slight tingle was detected when they touched the more sensitive skin areas, such as around the lips or under the arms. No redness resulted.
Table 1. Extremes of physical/chemical parameters at different depths in Kaiser Pond when *Crasedacusta sowerbii* was present in 2001.

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<td>21 - 31</td>
<td>0.2 - 6.9</td>
<td>6.9 - 7.4</td>
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Quantitative samples of the medusae were collected on 17 dates between 8 August through 7 November, when the last specimens were found. Distribution was patchy and density for individual plankton tows varied from zero on 7 September, 22 October, 5 November and 7 November to 121.32/m³ on 9 September (Table 2). Mean density for each collection date varied from 0.59/m³ on 7 September and 7 November to 34.43/m³ on 22 August (Table 2).

On 15 October, 11 different plankton tows were taken at 15 to 30 minute time intervals from the east pier (Table 3). Collection began at 09:30 a.m. and ended at 12:15 p.m. During the first five tows the sky was clear and no cloud cover occurred. By the sixth tow cloud cover began to move in and by the 11th tow 100 percent cloud cover existed and rainfall occurred. The density of *C. sowerbii* was significantly lower when no cloud cover existed than during the later six tows when cloud cover was increasing (Man-Whitney *U* test, *r*=15, *P*=0.004). The Spearman rank order correlation coefficient between density and percent cloud cover was *r*=0.744, *P*=0.0068. The positive relationship between density and percent cloud cover may have been a phototactic response to decreasing light conditions. It also could have been due to an upward migration following their zooplankton food source in the water column due to changing light conditions. These data (Table 3) also suggest that the other density measurements (Table 2), which were collected at different times between 08:00 and 13:30 hours under various light conditions, are not representative of the density at all depths.

One specimen of a newly budded medusa, 1 mm in diameter with only four tentacles, was observed in a plankton sample collected 5 October. Five polyps were found on one of the artificial substrates that had been out for seven weeks at one meter depth. No polys were found on the other substrates. The size of the polyps ranged from 0.6 to 1.1 mm long and the entire body, except for the area around the oral
Table 2. Mean and extreme densities (No./m$^3$) of Craspedacusta sowerbii in Kaiser Pond for each date during 2001. $n =$ number of tows.

<table>
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<td>6</td>
<td>4.33</td>
<td>0 - 8.26</td>
</tr>
<tr>
<td>Oct. 29</td>
<td>8</td>
<td>10.47</td>
<td>7.08 - 15.33</td>
</tr>
<tr>
<td>Nov. 5</td>
<td>6</td>
<td>0.79</td>
<td>0 - 2.36</td>
</tr>
<tr>
<td>Nov. 7</td>
<td>4</td>
<td>0.59</td>
<td>0 - 1.18</td>
</tr>
</tbody>
</table>

Table 3. Density of Craspedacusta sowerbii in individual plankton tows collected at 15 to 30 minute intervals under different cloud cover (light) conditions on October 15, 2001.

<table>
<thead>
<tr>
<th>Tow No.</th>
<th>Time</th>
<th>No./m$^3$</th>
<th>% Cloud Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>09:15 a.m.</td>
<td>4.72</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>09:30</td>
<td>3.54</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>09:45</td>
<td>4.72</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>10:00</td>
<td>2.36</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>10:15</td>
<td>5.90</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>10:30</td>
<td>10.60</td>
<td>20</td>
</tr>
<tr>
<td>7</td>
<td>10:45</td>
<td>3.54</td>
<td>30</td>
</tr>
<tr>
<td>8</td>
<td>11:00</td>
<td>30.67</td>
<td>50</td>
</tr>
<tr>
<td>9</td>
<td>11:20</td>
<td>55.44</td>
<td>50</td>
</tr>
<tr>
<td>10</td>
<td>11:45</td>
<td>8.26</td>
<td>75</td>
</tr>
<tr>
<td>11</td>
<td>12:15 p.m.</td>
<td>96.72</td>
<td>100 (rain)</td>
</tr>
</tbody>
</table>

opening that contained nematocycts, was covered with detritus and difficult to see. One polyp specimen consisted of two zooids and the others were single zooids. The presence of the polyps on the suspended substrate indicates that sexual reproduction had occurred.

Phytoplankton were always very sparse in the water column, except on 5 October, when a bloom of the yellow-green algae Dinobryon occurred. Zooplankton, including cladocerans, copepods and the rotifer Keratella, were present in high numbers throughout the study and were still abundant when the medusae disappeared. This suggests that food was not a limiting factor. Acker & Muscat (1976) reported that water
temperature affected the occurrence and survival of the different life cycle stages of *C. sowerbii*. They listed the minimum and maximum temperatures for the medusae as 15 and 30°C, respectively. In Kaiser Pond the temperature extremes when the medusae were present varied from 21 to 33°C.

ACKNOWLEDGMENTS

I thank James and Francis Kaiser for access to their pond. Stephanie Bennie, Vickie Bordelon, Ana Christensen, David Hicks, Steven Lewis and Becky Wolff assisted in fieldwork. Paul Nicoletto criticized the manuscript.

LITERATURE CITED


A SCIENTIFIC COMPARISON OF CENTRIFUGALLY CAST FIBERGLASS REINFORCED POLYMER PIPE AND BAR WRAPPED CONCRETE CYLINDER PIPE USING FINITE ELEMENT ANALYSIS

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Composite materials have gained popularity in industry over the past fifteen years. They are being used in rehabilitation of existing structures and the design of new ones. Much research has been done on the use of fiber reinforced polymers (FRP) to rehabilitate and strengthen concrete columns, piers, bridge decks and to protect dock fenders. Until recently, very little research has been done pertaining to the use of FRP in piping applications, particularly for pressure-flow applications.

Two kinds of FRP are commonly used; carbon-based and fiberglass-based composites. This paper focuses on centrifugally cast fiberglass reinforced polymer (CCFRPM) pipe and looks closely at large diameter (64-inch) pipe subjected to pressure-flow applications. A general comparison is given in Table 1. A typical application is presented using finite element analysis to compare CCFRPM pipe to concrete bar wrapped cylinder pipe (B-303 Pipe) (Table 2). The simulation models the behavior of large diameter pipe under pressure-flow conditions on an elastic foundation. Resulting stresses and deflection of the CCFRPM pipe are compared to those of the B-303 Pipe.

The following example is used to illustrate key differences between B-303 and CCFRPM pipe. Consider the design of a waterline main with a 64-inch inside diameter subjected to a 150 psi working pressure and a 75 psi surge pressure. The system is assumed to have soil cover conditions varying from 6 feet to 14 feet and is subjected to American Association of State Highways and Transportation Officials (AASHTO) HS-20 highway loading. The overburden soil has a unit weight of 120 pcf. The cross-sectional area of the B-303 pipe is designed in
Table 1. General comparison of B-303 and CCFRPM pipes.

<table>
<thead>
<tr>
<th></th>
<th>B-303 Pipe</th>
<th>CCFRPM Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside Diameter</td>
<td>64 inch</td>
<td>64 inch</td>
</tr>
<tr>
<td>Wall Thickness</td>
<td>2.5 inch</td>
<td>1.5 inch</td>
</tr>
<tr>
<td>Young’s Modulus (E)</td>
<td>2,350 ksi</td>
<td>4,000 ksi</td>
</tr>
<tr>
<td>Maximum Allowable Deflection of Cross-section</td>
<td>1.1 inch</td>
<td>3.2 inch</td>
</tr>
<tr>
<td>Maximum Allowable Externally Applied Load</td>
<td>14,700 lb/LF</td>
<td>14,700 lb/LF</td>
</tr>
</tbody>
</table>

Table 2. Finite element analysis therefore yields the following results.

<table>
<thead>
<tr>
<th></th>
<th>B-303 Pipe</th>
<th>CCFRPM Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Bending Stress</td>
<td>36.27 ksi</td>
<td>27.19 ksi</td>
</tr>
<tr>
<td>Maximum Shearing Stress</td>
<td>14.85 ksi</td>
<td>10.73 ksi</td>
</tr>
<tr>
<td>Maximum Deflection</td>
<td>1.323 inch</td>
<td>2.68 inches</td>
</tr>
</tbody>
</table>

accordance with the method outlined in American Water Works Association (AWWA 1995) M9 standard C-303 for concrete bar wrapped cylinder pipe. Design yielded a 2.5 inch wall thickness. The inner steel cylinder is 0.353 inch thick, and the steel helical wrap was 5/8 inches in diameter on a 1 2/3 inch center to center spacing. The cross section of the CCFRPM pipe was designed according to AWWA specifications and manufacturer’s guidelines. The wall thickness is 1.5 inches and the Young’s Modulus is 2,350 ksi.

STAAD-III computer software is used to model a 20 foot long pipe section with a 64 inch inside diameter. This version of STAAD (STAAD-III, 1995) does not support circular or radial elements. Therefore, the circular pipe cross-section was approximated using a 32 sided polygon. A three-dimensional mesh surface was generated having 6.28 inch by 12 inch elements. It is assumed that soil bedding conditions offered support over the bottom half of the pipe. Soil spring coefficients are calculated using a soil subgrade modulus of 250 kip/sf/foot of deflection and projecting element areas in both the $x$ and $y$ directions. This simulated bedding conditions act in the radial direction on the bottom half of the pipe. External loads due to soil overburden are next calculated for both six feet and fourteen feet of cover. The model is then run using several loading combinations of dead and live loads to ensure those worst-case scenarios are considered and that maximum stress and deflection are obtained within the system.
Note that the deflection of the B-303 pipe exceeded allowable deflections. This indicates that the soil stiffness modeled in STAAD is not adequate to prevent the pipe from deflecting, and pipe bedding conditions require re-evaluation if this pipe were to be installed.

**CONCLUSIONS**

The following conclusions can be drawn from the above finite element analysis and supporting background information.

1. CCFRPM Pipe is a less dense and less rigid system than B-303 pipe.
2. CCFRPM Pipe yielded lower stresses and higher deflections in finite element analysis than did the B-303 pipe with the same inside diameter subjected to the same internal pressure and external loading conditions.
3. CCFRPM Pipe is a viable alternative for large diameter pipe under pressure applications.
4. Additional research is required before CCFRPM pipe will become widely used in industry. Much work is required to develop design standards and guidelines to ensure its safe and economical use.

**LITERATURE CITED**


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* * * * *

**NOTEWORTHY RECORDS OF MAMMALS FROM THE ROLLING PLAINS OF TEXAS**

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The southern Rolling Plains of north central Texas is an area of transition from eastern forest to western grassland mammalian species. This region is characterized by level to rolling plains with extensions of
eastern riparian habitats and open stands of mesquite (Blair 1950). There are isolated outcroppings of Edwards Plateau limestone in the southern portion of the Rolling Plains (Matthews 1960). Specimens were collected in habitats consistent with those of central Texas as described by Hanson et al. (1998). All specimens documented within this report represent county records or minor range extensions based on data from Davis & Schmidly (1994) and subsequent publications. Study skins and skeletal material are deposited in the Abilene Christian University Natural History Collection (ACUNHC) and the Hardin-Simmons University, Collection of Vertebrates (HSUCV).

*Cryptotis parva.*—The least shrew occurs throughout the eastern and central portions of Texas and its range extends west in the Panhandle into New Mexico and south along the Rio Grande (Davis & Schmidly 1994). Revelez & Dowler (2001) report range extensions into the Edwards Plateau in Tom Green and Concho counties. *Cryptotis parva* inhabits grassland and seldom occurs in forests (Davis & Schmidly, 1994). The specimens reported here (ACUNHC 193 and 224) were salvaged from a cat (which is consistent with other reported records) in Albany, and represent the first from Shakelford County.

*Notiosorex crawfordi.*—The distribution of the desert shrew includes the more arid, western and southern regions of the state in areas with available cover of *Opuntia* cactus (Davis & Schmidly 1994). Records in Texas are spotty, possibly due to standard methods of trapping which are not often conducive to catching shrews (Goetze 1998). Collection of a single specimen occurred using pitfall traps in an area of mesquite (*Prosopis* sp.) and mixed grass vegetation in proximity to natural and man-made cover. Thornton & Lee (1996) reported extension of the range of *N. crawfordi* (ACUNHC 90) east into Callahan County. The collections of this species in southern Taylor County, 3 miles east of Bradshaw (ACUNHC 783) supports a more widespread occurrence in the southern Rolling Plains.

*Lasiurus borealis.*—The eastern red bat is found in woodlands and riparian habitats (Goetze 1998). It is considered a year-round resident of east Texas; however, it is highly migratory and may be only a summer migrant to the western half of the state (Schmidly 1991). The specimen (ACUNHC 555) was hit by a U.S. mail truck in Brown County 10 miles north of Brownwood. Brown County is located along the ecotone of the Edwards Plateau and the Rolling Plains (Blair 1950).
Sylvilagus floridanus.—The eastern cottontail is found throughout Texas. It is an inhabitant of brushy agriculture regions and riparian habitats usually not far from water (Davis & Schmidly 1994; Goetze 1998). Taylor County is a mosaic of agriculture, grassland and brush providing ample habitat for this species. The specimen documented here (ACUNHC 127) was collected from Taylor County (no specific locality) in 1969.

Lepus californicus.—The black-tailed jackrabbit is common statewide except for the Big Thicket region (Davis & Schmidly 1994). This species is common on the Rolling Plains, but not well documented. This report documents county records for \textit{L. californicus} collected in 1969 from Taylor County no specific locality (ACUNHC 126) and collected in 1996 from Callahan County; 3 miles south of Putnam (ACUNHC 397).

Perognathus merriami.—The distribution of Merriam’s pocket mouse is known from the western two-thirds of the state, but it is absent from the extreme northern Panhandle and western Trans-Pecos due to the presence of \textit{Perognathus flavus} (Lee & Engstrom 1991; Davis & Schmidly 1994). It is common in rocky habitats with sparse ground cover and short to mid-height grasses (Goetze 1998). Collection of this specimen from 2 miles north Lake Abilene (ACUNHC 780) was in a juniper-dominated community with mid height grasses and rock outcrops of Triassic origin. Taylor County is within the range of \textit{P. merriami} and parts of the county are consistent with its typical habitat. This specimen, however, represents the first record for Taylor County. Furthermore, we also report on a specimen of \textit{P. merriami} from Jones County; Dub Wofford Ranch, 32° 40’ N, 99° 39’W (HSUCV 173) collected in 1970.

Sigmodon hispidus.—The hispid cotton rat is widespread in Texas (Davis & Schmidly 1994). Specimens collected in 2001 from Hawley (ACUNHC 785, 786) and in 1970 from Dub Wofford Ranch, 32° 40’ N, 99° 39’W (HSUCV 13) represents the first record for Jones County. The habitat from which the Hawley specimen was taken was highly disturbed by mowing and the planting of pine trees.

Peromyscus pectoralis.—The white-ankled mouse was collected in Jones County, Hawley (ACUNHC 790). This specimen was found at the northwestern limits of the species’ range in Texas (Davis & Schmidly
1994) and was taken from the same trap line as the above mentioned *S. hispidus* near Hawley.

*Neotoma micropus.*—The southern plains woodrat prefers open grass and brush habitat that is common in Jones County. The first specimens (HSUCV 165, 271) collected in this county were from the Dub Wofford Ranch, 32° 40’ N, 99° 39’W.

*Baiomys taylori.*—The northern pygmy mouse has been documented in the southern Rolling Plains (Davis & Schmidly 1994; Hanson et al. 1998; Revelez & Dowler 2001). The undocumented presence of this common species indicates how poorly the mammal fauna of Jones County is known. The specimen (HSUCV 334) was collected in 1970, Jones County; Dub Wofford Ranch, 32° 40’ N, 99° 39’W.

*Procyon lotor.*—The common raccoon is present throughout the state (Davis & Schmidly 1994). It is common in riparian habitats or wooded areas, abandoned farmlands, and often around humans (Goetze 1998). Distribution is influenced more by the presence of water than by the type of vegetation (Davis & Schmidly 1994). A specimen representing a county record (ACUNHC 584) was collected 4 miles south Putnam in an oak-juniper-dominated community of Callahan County.

**LITERATURE CITED**


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* * * * *
RECENT RECORDS OF BATS FROM THE LOWER CANYONS OF THE RIO GRANDE RIVER OF WEST TEXAS

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*Department of Biological Sciences and the Museum of Texas Tech University
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Past surveys of mammals in Brewster and Terrell counties, Texas, focused primarily on the mountains and surrounding lowland desert habitats, the tributaries to the Rio Grande and their associated canyons, and sections of the Rio Grande within the boundaries of Big Bend National Park (Bailey 1905; Borrell & Bryant 1942; Schmidly et al. 1976; Schmidly & Ditton 1979; Hollander et al. 1990; Higginbotham & Ammerman 2002). These investigations did not include the Lower Canyons section of the Rio Grande.

The Lower Canyons region of the Rio Grande stretches for approximately 100 km from Reagan Canyon, just east of La Linda, Brewster County, and continues east-northeast to the Dryden crossing takeout, east of San Francisco Canyon, Terrell County. This section of the Rio Grande marks a gradual transition from the Chihuahuan Biotic Province towards a landscape that becomes increasingly characteristic of the convergence zone between the Balconian and Tamaulipan biotic provinces described by Blair (1940; 1950) and Dice (1943). The combination of these different ecosystems has the potential to support high species diversity. Additionally, along the banks of the river, the native riparian vegetation has been impacted by recent invasions of exotic plant species, such as salt cedar (Tamarix sp.) and giant cane (Arundo donax), which also contribute to plant diversity along the Rio Grande. The Rio Grande Wild and Scenic River historically served as an important biogeographic barrier along the U.S.-Mexican border (Schmidly 1977), but recent changes due to impoundments, irrigation, invasion of non-native plants, and pollution potentially have altered this riparian ecosystem and the occurrence of animal and plant species (Schmidly & Ditton 1979).

There are no published accounts of bats for the Lower Canyons
stretch of the Rio Grande. However, several investigators recently reported unexpected bat species from nearby (Yancey et al. 1995; Dowler et al. 1999; Higginbotham et al. 1999; Jones & Bradley 1999; Jones et al. 1999). These findings suggest that bat distributions are changing in Texas. However, these distributional shifts are still not understood and may simply reflect an increase in the knowledge of bat distributions as a result of increased survey efforts in these areas. This report notes the occurrence of 13 bat species in the Lower Canyons of the Rio Grande, including two new records from Terrell County.

A series of three surveys, 30 October to 4 November 1999, 19-22 March 2001 and 7-12 October 2001, were conducted with the assistance of the National Park Service. Mist-nets were placed at a total of eight sites over or along the banks of the river, at mouths of canyons, and/or over shallow pools. Captured bats were identified to species, sexed, aged, and measured using standard procedures (Handley 1988). Voucher specimens were deposited in the Angelo State Natural History Collection (ASNHC), Angelo State University.

From 30 October to 4 November 1999, a total of 18 bats was captured. From 19-22 March 2001 there was a total of 44 captures. The period of 7-12 October 2001 produced a total of 38 captures. Species caught (in order of decreasing abundance) were Myotis yumanensis, Antrozous pallidus, Tadarida brasiliensis, Mormoops megalophylla, Corynorhinus townsendii, Lasiusurus cinereus, Nyctinomops femorosaccus, Nyctinomops macrotis, Pipistrellus hesperus, Myotis californicus, Myotis thysanodes, Myotis velifer and Lasionycteris noctivagans. Details of the occurrence of M. megalophylla, N. femorosaccus, M. thysanodes, C. townsendii, M. californicus and L. noctivagans, are described below. Terrell County records include M. megalophylla and N. femorosaccus.

*Mormoops megalophylla.*—Ghost-faced bats are known in Texas from the southern Trans-Pecos region, the southern edge of the Edwards Plateau, and extreme south Texas (Davis & Schmidly 1994). Two adult females were captured, one on 11 October 2001 (River Mile 710.5; 29°52'47"N, 102°19'12"W) and another (ASNHC 11581) on 12 October 2001 (River Mile 698; 29°50'51.3"N, 102°11'0.7"W). Although records have been reported for surrounding counties, Brewster and Val Verde, these captures represent the first reported for Terrell
County. Other bats captured in the same night included *M. yumanensis*, *A. pallidus*, *T. brasiliensis*, *N. femorosaccus* and *P. hesperus*.

*Nyctinomops femorosaccus*.—Within the United States, pocketed free-tailed bats have only been reported from Big Bend National Park, Brewster County, Texas, along with localities in southern California, southern Arizona and southeastern New Mexico (Schmidly 1991; Davis & Schmidly 1994). Five bats (2 subadult males, 2 subadult females and 1 adult female) were caught on 11 October 2001 (River Mile 710.5; 29°52’47”N, 102°19’12”W). One subadult male was collected (ASNHC 11587). This specimen represents the first reported for Terrell County. These captures also represent the most eastern records of the species in the United States. Other bats captured in the same night were *M. yumanensis*, *A. pallidus*, *T. brasiliensis*, *M. megalophylla* and *P. hesperus*.

*Myotis thysanodes*.—The fringed myotis is a migratory species that generally is known in the Trans-Pecos to arrive in April and depart in October (Easterla 1973; O’Farrell & Studier 1980). On 20 March 2001, one adult male (ASNHC 11517) was collected (River Mile 723.2; 29°46’17”N, 102°23’54”W). This record extends the seasonal occurrence of *M. thysanodes* in the Trans-Pecos region.

*Corynorhinus townsendii*.—The genus *Corynorhinus* is used (instead of *Plecotus*) due to recent taxonomic revision (Bogdanowicz et al. 1998; Hoofer & Van Den Bussche 2001). In Texas, Townsend’s big-eared bat is known from the Trans-Pecos and Plains regions (Davis & Schmidly 1994). An adult female (ASNHC 11525) was taken in Brewster County within 300 meters of the Brewster-Terrell County line (River Mile 710.8; 29°53’17.2”N, 102°20’16.2”W) on 3 November 1999. This specimen represents the easternmost record of this species within Brewster County and suggests its range extends into Terrell County. Other bats caught in the same night were *T. brasiliensis*, *N. femorosaccus*, and *M. californicus*.

*Myotis californicus*.—Within Texas, the California myotis is found mainly in the Trans-Pecos region with one record from the Panhandle (Davis & Schmidly 1994). An adult male (ASNHC 11512) was collected within 300 meters from the Brewster-Terrell County line
(River Mile 710.8; 29°53'17.2"N, 102°20'16.2"W) on 3 November 1999. This specimen represents the eastern-most record of this species within Brewster County and suggests a possible occurrence in Terrell County. Other bats caught in the same night were *T. brasiliensis*, *N. femorosaccus* and *C. townsendii*.

*Lasionycteris noctivagans*.—Silver-haired bats are thought to have a wide distribution in Texas based on scattered localities across the state (Schmidly 1991; Davis & Schmidly 1994). Dowler et al. (1992) reported two males northeast of Dryden within Terrell County. One adult male (ASNHC 11505) (River Mile 698; 29°50'54"N, 102° 11'01"W) was collected in Terrell County on 22 March 2001. This capture represents the third record reported for the county. Other bats caught in the same night were *T. brasiliensis*, *M. yumanensis*, *A. pallidus* and *M. velifer*.

This investigation contributes to the current understanding of the distributions of bat species along the Lower Canyons region of the Rio Grande Wild and Scenic River in Texas. The Rio Grande has experienced substantial change throughout the last century; changes that could severely impact the river’s water flow, wildlife potential, and integrity of the native vegetation. As the vegetation continues to change due to invasion of non-native species like salt cedar (*Tamarix* sp.) and giant cane (*Arundo donax*), distributions of bats (and other organisms) are likely to be affected.

ACKNOWLEDGEMENTS

We thank the National Park Service personnel, especially Michael Ryan and Stephen McAllister, at Big Bend National Park for their assistance, loan of equipment and for guiding us safely down the river. Raymond Skiles and Marcos Paredes provided logistical support. These surveys were conducted in cooperation with the National Park Service under a resource activity permit. Collection permits were issued by the Texas Parks and Wildlife Department (# SPR-0994-703). Scott Burt, Michael Dixon, David Long, Michael Moreno and Bryan Reece provided valuable field assistance. We also thank Robert Bradley, Robert Dowler and Frank Yancey for providing comments on a previous version of this manuscript.
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THE TEXAS JOURNAL OF SCIENCE

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This index has separate subject and author sections. Words, phrases, locations, proper names and the scientific names of organisms are followed by the initial page number of the article in which they appeared. The author index includes the names of all authors followed by the initial page number of their respective article(s).

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