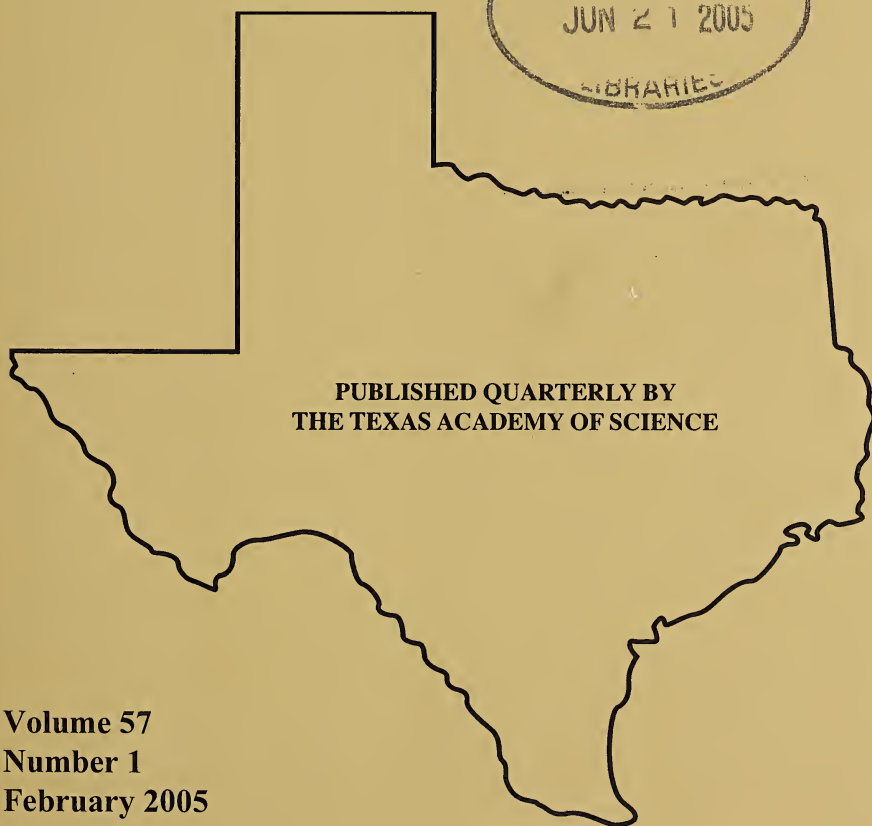
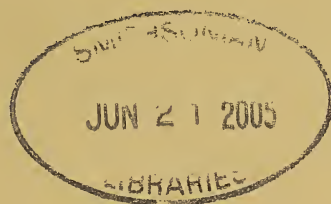


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DISTRIBUTIONAL RECORDS AND COMMENTS ON OKLAHOMA MAMMALS

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Abstract.—This report presents a review of regional and national mammal collections to update the distributions of Oklahoma mammals. Eighty-four (84) unreported county records representing 37 species were found. New localities represent all but one major physiognomic region of the state. Range extensions were found for four species and sight records or observations were confirmed for four species. The addition of these records expands the understanding of mammals in Oklahoma.

The geographic position of Oklahoma is such that three major biotic areas (deciduous woodlands, Great Plains, and Rocky Mountain region) occur in the state. This crossroads makes this region of North America biologically significant and ideal for research dealing with the influence(s) of global climate change. However, the mammalian fauna of Oklahoma perhaps is less well known than that of many other states. Unlike the nearby states of Texas and New Mexico, no formal biological survey of the state was undertaken. Even after approximately 100 years of collecting, few regions have been well surveyed and there is a paucity of taxonomic, distributional, and natural history information for most species.

The earliest compilation of the mammals of Oklahoma based on validated records was that of Elliot (1899). Forty years later, Blair (1939) published the first comprehensive listing of the mammalian diversity in the state. The second major review of the state's mammal fauna was published 50 years later by Caire et al. (1989). Since the publication of the *Mammals of Oklahoma* by Caire et al. (1989), significant records have contributed to a better understanding of the mammalian diversity in Oklahoma (e.g., Bradley et al. 1988; Gettinger 1991; Smith 1992; Stangl et al. 1992; Kasper et al. 1993; Thies et al. 1993; Tumilson et al. 1993; Tyler 1994; Caire & Sloan 1996; Smith 1996; Tyler & Donelson 1996; Tyler & Joles 1997; Payne et al. 2001; Tyler & Haynie 2001). In addition to adding new county records and extending known geographic ranges,

species listed as of probable occurrence by Caire et al. (1989) have been reported in the state (e.g., *Sorex longirostris* by Taylor & Wilkinson 1988; *Mustela nivalis* by Clark & Clark 1988).

A search of eight regional and national mammal collections has revealed 84 unreported county records representing 37 species from Oklahoma. New records are reported in all major physiognomic regions of the state (Caire et al. 1989), except the mesquite-grass plains. Range extensions are reported for Elliot's short-tailed shrew (*Blarina hylophaga*), the pallid bat (*Antrozous pallidus*), the western harvest mouse (*Reithrodontomys megalotis*), and the woodland vole (*Microtus pinetorum*). Sight records or observations are confirmed for the silver-haired bat (*Lasionycteris noctivagans*), the nine-banded armadillo (*Dasypus novemcinctus*), southern flying squirrel (*Glaucomys volans*), and North American porcupine (*Erethizon dorsatum*). The addition of these records expands the understanding of mammals in Oklahoma.

METHODS AND MATERIALS

Mammalian species accounts are arranged according to Wilson & Reeder (1993). Common name usage follows Wilson & Cole (2000). Because many distributions have been significantly altered, a brief description of the mammal's range in Oklahoma is given followed by a summary of records reported subsequent to Caire et al. (1989). Unless indicated otherwise, all specimens represent the first record(s) of the species for the counties reported. The specimens are listed alphabetically. Voucher specimens are deposited in the following collections (Hafner et al. 1997): University of Oklahoma, Oklahoma Museum of Natural History (OMNH); Carnegie Museum of Natural History (CM); The Field Museum (FMNH); University of Kansas, Museum of Natural History (KU); University of New Mexico, Museum of Southwestern Biology (MSB); University of California, Berkeley, Museum of Vertebrate Zoology (MVZ); Texas Tech University, Museum of Texas Tech University (TTU); and the United States National Museum of Natural History

(USNM). Specimens not examined by the authors are indicated with an asterisk.

SPECIES ACCOUNTS

Didelphis virginiana

The distribution of the Virginia opossum includes all of Oklahoma, although no specimens are known for about one-third of the counties, especially those in the western part of the state. Stangl et al. (1992) noted county records for Greer and Jefferson counties. New county records are reported here for Blaine and Love counties.

Material examined.—Blaine County: 4 mi N, 4 mi W of Watonga, 1 specimen (MVZ 80746); 6 mi N, 5 mi W of Watonga, 1 specimen (MVZ 80747). Love County: 1 mi W, 2 mi N of Powell, 1 specimen (OMNH 15054; specimen deaccessioned).

Dasyus novemcinctus

The nine-banded armadillo has been reported in a variety of habitats throughout much of Oklahoma, but few specimen records exist for most parts of the state. This species was first reported for Greer, Jackson, Jefferson, and Roger Mills counties by Stangl et al. (1992), for Harper County by Tyler & Donelson (1996), and for Osage County by Payne et al. (2001). The first observations of this species were reported for Washita County by Clark & Tumilson (1992) and for Beaver and Woods counties by Tyler & Donelson (1996).

New records are reported for the counties of Beckham, McClain, Rogers, and Seminole, which expand the understanding of the distribution of the nine-banded armadillo in Oklahoma. The previous data for Rogers County was based on a sight record (Blair 1936; Tyler & Donelson 1996); the specimen reported represents the first known for the county.

Material examined.—Beckham County: 12.75 mi S, 3.5 mi E of Erick, 600 m, 1 specimen (OMNH 29926). McClain County: 16 mi S of Blanchard on Hwy 76, 1 specimen (OMNH 16544). Rogers County: 3 mi W of Inola, 1 specimen (MSB 113493). Seminole County: 2 mi W of Seminole, 1 specimen (TTU 39666); 0.5 mi E of Tecumseh on Hwy 9, 1 specimen (OMNH 29065).

Blarina hylophaga

Elliot's short-tailed shrew is distributed in the eastern two-thirds of the state, although records for many of the counties, especially in western parts of the state, are lacking. Stangl et al. (1992) and Stangl & Carr (1997) reported records for the counties of Grady and Okmulgee, respectively. New county records are reported here for Craig, Major, Mayes, and Seminole counties. The specimen from Major County represents the most northwestern record in the state, extending its range to the Panhandle of Oklahoma.

Caire et al. (1989) cited a literature record for McClain County possibly in reference to the record given by Blair (1939) 7 mi S of Norman. However, no such specimen(s) could be located in the OMNH collection. George et al. (1981) reported two specimens from 8 mi W of Norman from the Pittsburg State University collection that may have been vouchered from the ecological study of H. A. Hays (Hays 1958).

Material examined.—Craig County: 8.5 mi N, 1.5 mi W of Welch, 1 specimen (TTU 64668). Major County: 3 mi S of Ames, 1 specimen (OMNH 26415). Mayes County: ca. 5 km E of Chouteau, 1 specimen (OMNH 14501/14504). Seminole County: 2 mi W of Seminole, 1 specimen (TTU 39663).

Cryptotis parva

Records reported herein, and those reported since the publication of Caire et al. (1989) have expanded the known distribution of this shrew to include nearly the entire state. New records are reported

for Hughes, McClain, Murray, and Roger Mills counties. This species was first reported for Cotton, Greer, Stephens, and Tillman counties by Stangl et al. (1992), for Beaver and Texas counties by Dalquest et al. (1990), and for Caddo County by Smith (1993).

The locality for the literature record for McClain County (Caire et al. 1989) is 7 mi S of Norman based on Blair (1939). However, no specimens could be located in the OMNH collection. Thus, the specimen reported for McClain County represents the only specimen known from this county.

Material examined.—Hughes County: 4.5 mi E of Wetumka, 2 specimens (TTU 56495, 56496). McClain County: T9S, R8E, Sec. 3, 1 specimen (OMNH 26617). Murray County: Rock Creek Campground, Platt National Park, Sulphur, 1 specimen (KU 79748). Roger Mills County: 8.5 mi N, 2.75 mi W of Cheyenne, Dead Indian Creek, 630 m, 1 specimen (OMNH 29795).

Notiosorex crawfordi

Specimens of the desert shrew from Oklahoma are uncommon; the distribution includes western Oklahoma, including the Panhandle, and a locality in southeastern Oklahoma (Pushmataha County) (Caire et al. 1989). A new record is reported here from southwest of the Foss Reservoir in Custer County in western Oklahoma.

Material examined.—Custer County: T13N, R20W, Sec. 22, SE1/4, 1 specimen (OMNH 22127).

Scalopus aquaticus

The eastern mole occurs statewide, although records in southwestern Oklahoma and the Panhandle have only recently been reported (Dalquest 1990; Clark & Tumblison 1992). This species was first reported for Cotton and Jefferson counties by Stangl et al. (1992) and for Washita County by Clark & Tumblison (1992).

Dalquest et al. (1990) reported specimens from Cimarron County. New records are presented for the counties of Delaware, Kiowa, and Roger Mills.

Material examined.—Delaware County: Arkansas-Oklahoma boundary, 5 mi S of Southwest City, Missouri, 1 specimen (KU 90537). Kiowa County: Quartz Mountain State Park, 1 specimen (OMNH 22172). Roger Mills County: Strong City, 1 specimen (OMNH 14550).

Antrozous pallidus

The pallid bat is found in the western United States and northern Mexico. In Oklahoma, there are few reported records for this species (Caire et al. 1989). The record below is the first for Payne County and represents one of the easternmost records in the distribution of this species.

Material examined.—Payne County: Stillwater, 1 specimen (FMNH 85519).

Eptesicus fuscus

Although the big brown bat is found throughout the United States and Canada southward to northern South America, its distribution in Oklahoma remains spotty. Most records are from the northern and far eastern portions of the state (Caire et al. 1989). New records are reported for Caddo, Cleveland, and Payne counties. The Caddo County specimens were collected in late September and late October, respectively. The specimens from Cleveland County were collected in mid-December and mid-August. The former was caught in the Art Museum basement.

Material examined.—Caddo County: Ryburn cliff, Rt. 152, 1 specimen (OMNH 16297); 5 mi E, 1 mi N of Binger, 1 specimen (OMNH 16775). Cleveland County: Norman, 2 specimens (OMNH 16785, 18538). Payne County: Stillwater, 1 specimen (FMNH 85520).

Lasionycteris noctivagans

The silver-haired bat generally occurs throughout most of the contiguous United States and southern Canada (Wilson & Ruff 1999) but is represented by few records in the southern portion of its range (Bee et al. 1981; Caire et al. 1989; Davis & Schmidly 1994). Only four specimens were known from Oklahoma in 1989 (Caire et al. 1989). Additional county records were reported for Cimarron County (11 specimens; Dalquest et al. 1990) and McCurtain County (one specimen; Sheffield & Chapman 1992). An individual was collected in November 2002 from Oklahoma County, known only to occur in the county previously from an observation record. Two individuals recently were captured in mid-September 2004 in Beaver County.

Material examined.—Beaver County: 3.9 mi S Floris, Beaver River Wildlife Management Area, 1 specimen (OMNH 32054); 3.9 mi S, 4 mi W Floris, Beaver River Wildlife Management Area, 1 specimen (OMNH 32055). Oklahoma County: Tinker Air Force Base, Oklahoma County, 1 specimen (OMNH 29930).

Lasiurus cinereus

The largest bat in Oklahoma, the hoary bat has the most widespread distribution of American bats, ranging from Canada to southern South America (Wilson & Ruff 1999). However, few records have been reported for Oklahoma (Caire et al. 1989). An individual was collected in September 1974 in Woodward County.

Material examined.—Woodward County: no specific locality, 1 specimen (OMNH 16525).

Myotis velifer

The cave myotis occurs throughout most of western Oklahoma, including the Panhandle (Caire et al. 1989). New records are reported for Caddo County.

Material examined.—Caddo County: 5 mi E of Binger, 1 specimen (OMNH 16776); Carnegie, 2 specimens (KU 43879, 43880); Ryburn Farm, Rt. 152, 1 specimen (OMNH 16291; tag #6019); Ryburn Cliff, Rt. 152, 12 specimens (OMNH 16285, 16288, 16289 tag #6110, 16290, 16292, 16293 tag “bat NEOSU TAH-74464”, 16294, 16295, 16296, 16869, 16874, 16885).

Nycticeius humeralis

This species is found most commonly in the eastern United States and probably reaches its westernmost limits in Oklahoma (Wilson & Ruff 1999), although recent records in Texas suggest this species is expanding its range westward (Revelez & Dowler 2001). The evening bat, like most bat species in the state, is represented by few specimens and few counties. Payne et al. (2001) reported the first records for Osage County. French & Bunyard (2002) reported the first observations for the counties of Caddo and Cleveland; the first voucher records are reported herein for Cleveland County, collected in August and October 2002.

Material examined.—Cleveland County: Richards Hall, University of Oklahoma Campus, Norman, 1 specimen (OMNH 29928); Bizzell Library, University of Oklahoma Campus, Norman, 1 specimen (OMNH 29929).

Pipistrellus hesperus

The western pipistrelle was known previously to occur only in southwestern Oklahoma, although its presence in the Panhandle was predicted by Caire et al. (1989), based on its close geographic proximity to localities in northeastern New Mexico, southeastern Colorado, and the Panhandle of Texas from which specimens had been collected. The first records for Cimarron County are reported. In Texas, the nearest record is located in Randall County (Davis & Schmidly 1994), approximately 100 miles to the south. Dalquest et al. (1991) took specimens from about three miles to the west of the Cimarron County locality, in Union County, New Mexico.

Material examined.—Cimarron County: 2.5 mi N, 1 mi E of Kenton, 3 specimens (OMNH 15737, 15761, 15762).

Canis latrans

The coyote is the largest and most common extant wild carnivore in Oklahoma (Caire et al. 1989). It has a statewide distribution and is well documented. A new record is reported here for Caddo County.

Material examined.—Caddo County: 1.5 mi N, 2 mi W of Ft. Cobb, 1 specimen (OMNH 14917).

Mephitis mephitis

Striped skunks are found throughout the state and are among one of the best-documented species in Oklahoma (Caire et al. 1989). Stangl et al. (1992) reported a new record for Jefferson County. An additional record is reported here from Garvin County.

Material examined.—Garvin County: 5 mi W of Wynnewood (DOR I-35 mile marker 57), 1 specimen (OMNH 15680).

Spilogale putorius

The eastern spotted skunk is distributed widely throughout the state (Caire et al. 1989) but records are scarce in both the northeast and southeast corners of the state (Tyler & Lodes 1980). Dalquest et al. (1990) reported the presence of this species in Cimarron County, and Tyler (1994) first reported it for Stephens and Osage counties. The first record for Rogers County is reported, representing the northeasternmost record for the state.

Material examined.—Rogers County: Inola Hill, T19N, R17E, Sec. 10, 1 specimen (MSB 113490).

Mustela vison

The distribution of the mink includes most of the eastern two-thirds of the state (Caire et al. 1989). Earlier, Stangl et al. (1992)

reported a specimen from Jefferson County. Along the edge of its westernmost range limits, the first records are reported here for Blaine and Cotton counties.

Material examined.—Blaine County: 4 mi N, 3 mi W of Watonga, 1 specimen (MVZ 80748); 6 mi N, 6 mi W of Watonga, 1 specimen (MVZ 80749). Cotton County: 1 mi W of Randlett, 1 specimen (MSB 24571).

Procyon lotor

Probably the most common of local carnivores, the raccoon can be found throughout the state (Caire et al. 1989). The first observations of *Procyon* in Washita County were reported by Clark & Tumblison (1992) and Stangl et al. (1992) reported the first records for Jefferson County. The first records are reported here for Murray and Rogers counties.

Material examined.—Murray County: 1.8 mi N of Turner Falls Park on Hwy 77, 1 specimen (OMNH 22982); no specific locality, 1 specimen (OMNH 16582). Rogers County: 3.5 mi SW of Inola, T19N, R16E, Sec. 30, 1 specimen (MSB 113486).

Odocoileus virginianus

The white-tailed deer has a widespread distribution in Oklahoma (Caire et al. 1989). Payne et al. (2001) first reported this species for Osage County. The first records for Creek, McClain, and Roger Mills counties are presented.

Material examined.—Creek County: 20 mi SW of Red Fork, 1 specimen (USNM 135751*). McClain County: 6 mi E of Lexington, 1 specimen (OMNH 16762). Roger Mills County: 9 mi N, 2.5 mi W of Cheyenne, Dead Indian Creek, 635 m, 1 specimen (OMNH 29794).

Sciurus niger

Eastern fox squirrels are found statewide except in the Panhandle (Caire et al. 1989). Despite its extensive distribution and abundance, these are the first records of the eastern fox squirrel for McClain County.

Material examined.—McClain County: 6 mi SW of Norman, 1 specimen (OMNH 16669); 1 mi E of Hwy 62, 1 specimen (OMNH 22148).

Glaucomys volans

Southern flying squirrels occur in the eastern half of the state, although relatively few records exist. The Rogers County record reported by Caire et al. (1989) was based on an observation published by Blair (1938; 1939) from the Twin Lakes area. This species was first reported for Jefferson and Murray counties by Stangl et al. (1992). The first observations of this species were reported for Cotton County by Stangl et al. (1992). The following represent the first records for the counties of Rogers and Seminole.

Material examined.—Rogers County: T19N, R16E, Sec. 30, 1 specimen (MSB 113394). Seminole County: 9.3 mi E of Seminole, 1 specimen (TTU 40682).

Chaetodipus hispidus

The hispid pocket mouse is found statewide except for the far northeastern and southeastern counties. This species was first reported for the counties of Greer and Stephens by Stangl et al. (1992), for Beaver County by Dalquest et al. (1990), and Washita County by Clark & Tumblison (1992). The following report is a new record for McIntosh County in eastern Oklahoma.

Material examined.—McIntosh County: 2.1 mi E of Dustin, 1 specimen (TTU 40804).

Perognathus flavus

The distribution of the silky pocket mouse has been modified since Caire et al. (1989). Synonymized by Wilson (1973), data provided by Lee & Engstrom (1991) suggests the recognition of Merriam's pocket mouse (*Perognathus merriami*) as a species distinct from *P. flavus*. While no formal investigation has led to the distributional limits for each species in the state, it is likely that both species are present in western Oklahoma. Other records reported in southwestern Oklahoma include those for Cotton County (Stangl et al. 1992) and Washita County (Clark & Tumblison 1992). This study reports new records for Beckham and Ellis counties.

Material examined.—Beckham County: 11.75 mi S, 2.5 mi E of Erick, Sandy Sanders Wildlife Management Area, 610 m, 4 specimens (OMNH 29851-29854). Ellis County: 2 mi N of Shattuck, 1 specimen (OMNH 2751).

Microtus pinetorum

The woodland vole is distributed in the eastern two-thirds of the state. New county records of the woodland vole were reported by Lutterschmidt et al. (1996; LeFlore County), Clark & Tumblison (1992; Washita County), and Stangl et al. (1992; Love and Murray counties). However, specimens from Murray County previously have been reported (see references in Blair 1939; Caire et al. 1989). New county records are reported here for Johnston, Kiowa, Major, McIntosh, Nowata, and Seminole counties. The specimens from Kiowa and Major counties occur outside of the known distribution and represent the westernmost records for this species in Oklahoma.

Material examined.—Johnston County: 9 mi E of Tishomingo, Blue R., 1 specimen (OMNH 16884); shoreline Murray 23, Tishomingo National Wildlife Refuge, 620 ft., 1 specimen (USNM 289002*). Kiowa County: 1.5 mi S, 0.8 mi W of Mountain View, 1 specimen (TTU 55123). Major County: 3 mi S of Ames, 2 speci-

mens (OMNH 25671, 25672). McIntosh County: 2 mi E of Raiford, 1 specimen (TTU 40809). Nowata County: 5.5 mi E, 1 mi S of Nowata, 1 specimen (OMNH 15119). Seminole County: 2 mi W of Seminole, 2 specimens (TTU 39669, 40811); 9.3 mi E of Seminole, 1 specimen (TTU 40812*).

Ondatra zibethicus

The distribution of the muskrat encompasses the majority of the state (excluding the Panhandle) but is most abundant in the northeastern portion of Oklahoma (Caire et al. 1989). New records are reported here for Canadian and Rogers counties.

Material examined.—Canadian County: Piedmont, 1 specimen (OMNH 19622). Rogers County: T19N, R16E, Sec. 24, 1 specimen (MSB 113476).

Neotoma floridana

The eastern woodrat occurs in all but the Panhandle and the westernmost counties of Oklahoma. Although this species was reported by Kasper et al. (1993) from the area around Welch, Craig County, no specific localities were given. The distribution in western and southern Oklahoma was clarified by Stangl et al. (1992) for Jefferson, Kiowa, and Love counties, and by Clark & Tumilson (1992) for Washita County. The first records for Craig, Garvin, and Seminole counties are reported.

Material examined.—Craig County: 9 mi N, 2 mi W of Welch, 2 specimens (TTU 64665*, 64669); 8.5 mi N, 1.5 mi W of Welch, 1 specimen (TTU 64671). Garvin County: 3.7 mi W, 5 mi S of Wynnewood, T1N, R1E, Sec. 7, NW 1/4, SE 1/4, 1 specimen (OMNH 16897). Seminole County: 2 mi W of Seminole, 2 specimens (TTU 39667, 39668); 1.1 mi W jct. 9 and 56, 2 specimens (TTU 54735, 54736); 9.3 mi E of Seminole, 1 specimen (TTU 40818).

Neotoma micropus

The southern plains woodrat generally occurs in drier regions of western Oklahoma (Caire et al. 1989). This study reports a new record for Ellis County.

Material examined.—Ellis County: 11 mi S, 3 mi E of Arnett, Packsaddle WMA, 685 m, 1 specimen (OMNH 26568); 12.5 mi S, 5 mi E of Arnett, Packsaddle WMA, 685 m, 1 specimen (OMNH 26569).

Oryzomys palustris

The marsh rice rat has a disjunct distribution in the state that primarily reflects the preferred habitat of the species. Gettinger (1991) reported the first records of this species for Carter, Coal, and Mayes counties. The latter record confirms the suggestion by Caire et al. (1989) that the rice rat would be found in northeastern Oklahoma. New records are reported for Choctaw and Okmulgee counties, which expand the distribution of this species to the north and west.

Material examined.—Choctaw County: 2 mi E of Swenk, swampy area on Hiway US 70, 1 specimen (KU 41375). Okmulgee County: 3.0 mi E of Dewar, Eufaula Wildlife Management Area, 3 specimens (TTU 62978-62980); 3.0 mi E of Dewar, T11N, R13E, Sec. 1, 1 specimen (TTU 64681); 1.0 mi S of Hoffman, Eufaula Wildlife Management Area, 1 specimen (TTU 62981).

Peromyscus attwateri

The distribution of the Texas mouse in Oklahoma is disjunct due to its preference for rocky habitats; it is found in eastern and southwestern parts of the state, but is absent from central Oklahoma. Stangl et al. (1992) reported the first record of the Texas mouse for Greer County. However, Caire et al. (1989) had cited a literature record from Schmidly (1973) for a specimen from

Quartz Mountain Park. New records are reported for the counties of Hughes, Okmulgee, and Seminole.

Material examined.—Hughes County: 2 mi E of Dustin, 2 specimens (TTU 45877, 45878); 2.1 mi E of Dustin, 8 specimens (TTU 39983-39985, 40741-40744, 40829); 2.1 mi E of Vivian, 1 specimen (TTU 39833); 4.5 mi E of Wetumka, 2 specimens (TTU 40854, 40855). Okmulgee County: 0.5 mi E of Henryetta, T11N, R13E, SEC 8, 17, 4 specimens (TTU 64682-64685). Seminole County: 3.4 mi E of Seminole, 2 specimens (TTU 39829, 39832); 3.5 mi E of Seminole, 2 specimens (TTU 55691, 55692); 9.3 mi E of Seminole, 2 specimens (TTU 39830, 39831).

Peromyscus leucopus

A new record is reported here for Grant County. With these records and those reported by Stangl et al. (1992) for Greer and Love counties, the white-footed mouse is known now from all counties in Oklahoma except Lincoln.

Material examined.—Grant County: 1 mi W, 2.9 mi S of Hawley, 1 specimen (OMNH 9146); 1 mi W, 1 mi N of Hawley, 3 specimens (OMNH 9147-9149); 1.4 mi W, 1.0 mi N of Hawley, 8 specimens (OMNH 9150-5157); 2 mi N of Pond Creek on Salt Fork River, 3 specimens (TTU 36808-36810) (these were cited by Baker et al. 1983).

Peromyscus maniculatus

The deer mouse is one of the most widespread species in the state. Stangl et al. (1992) reported first county records for Dewey and Stephens counties. However, the former was cited as a literature record by (Caire et al. 1989) based on specimens cited by Blair (1939). New records are reported here for the counties of Grant, Marshall, and McCurtain.

Material examined.—Grant County: 2.3 mi N, 8 mi W of Renfrow, 6 specimens (MSB 63118-63122, 63124); 2.3 mi N, 7.2 mi W of Renfrow, 4 specimens (MSB 63134-63137). Marshall County: 3.6 mi SE of Kingston, 1 specimen (OMNH 16753); Lake Texoma, Fobb Bottom, T8S, R4E, Sec. 12, 1 specimen (OMNH 15502); Fobb Bottom dune, T8S, R4E, Sec. 12, 1 specimen (OMNH 15503); dunes along Fobb Bottom, T8S, R4E, Sec. 12, 1 specimen (OMNH 15504); Univ. Okla. Bio. Stn., Willis, 1.5 mi E of Hwy 99 at Willis Br., 1 specimen (OMNH 15521). McCurtain County: 5.7 mi S of Broken Bow, 1 specimen (OMNH 6982); Beaver's Bend State Park, 6 specimens (OMNH 17054-17059).

Reithrodontomys fulvescens

The fulvous harvest mouse was thought to inhabit much of the southeastern two-thirds of the state in habitats ranging from mixed grass plains to oak-hickory forest. However, since Caire et al. (1989), the distribution has been expanded to include western Oklahoma. The distribution of this species in southwestern Oklahoma earlier had been clarified by Stangl et al. (1992) with county records published for Cotton, Grady, Greer, Kiowa, and Love counties. Clark & Tumlison (1992) reported new county records for Washita County. In northeastern Oklahoma, Thies et al. (1993) reported the first record for Osage County. New records are reported here for Beckham, Carter, Cherokee, Custer, Hughes, McIntosh, Okmulgee, Pawnee, Rogers, and Seminole counties. The specimens from Beckham and Custer counties are the northwesternmost records in Oklahoma. In the United States, the westernmost distribution of this species occurs in the Texas Panhandle just west of Beckham County (Schmidly 2002).

Material examined.—Beckham County: 13 mi S of Erick, Sandy Sanders Wildlife Management Area, 535 m, 2 specimens (OMNH 29862, 29863). Carter County: Lone Grove, 1 specimen (OMNH 29811). Cherokee County: Dogwood and Maple, Tahlequah, 1 specimen (OMNH 9357). Custer County: T13N, R20W, Sec. 22, S 1/4, 1 specimen (OMNH 16952). Hughes County: 4.5 mi E of

Wetumka, 2 specimens (TTU 54894, 54895); 5 mi E of Wetumka, 2 specimens (TTU 54892, 54893); 2.2 mi E of Raiford, 3 specimens (TTU 54889-54891); 2.1 mi E of Dustin; 2 specimens (TTU 39858, 45890). McIntosh County: 2 mi E of Raiford, 6 specimens (TTU 39482-39484, 45891, 45892, 55900); 3.1 mi E of Dustin, 2 specimens (TTU 54898, 54899). Okmulgee County: 3 mi E of Dewar, T11N, R13E, Sec. 1, 11 specimens (TTU 66069-66079); 0.5 mi E of Henryetta, T11N, R13E, Sec. 8, 1 specimen (TTU 62975); 0.5 mi E of Henryetta, T11N, R13E, Sec. 8, 17, 74 specimens (TTU 66080-66153); 1.5 mi S, 0.2 mi E of Hoffman, 6 specimens (TTU 66154-66159). Pawnee County: 1 mi S of Hallett, 1 specimen (TTU 38719). Rogers County: T19N, R16E, Sec. 13, 2 specimens (MSB 113428, 113429). Seminole County: 3.4 mi E of Seminole, 2 specimens (TTU 39862, 39863); 3.5 mi E of Seminole, 34 specimens (TTU 54861-54874, 54900-54919); 1.1 mi W jct. 9 and 56, 11 specimens (TTU 54850-54860).

Reithrodontomys humulis

The eastern harvest mouse has a distribution in the eastern United States that reaches its westernmost limits in central Oklahoma (Wilson & Ruff 1999). Caire et al. (1989) reported only three specimens of the eastern harvest mouse. Since 1989, this species was first reported for McCurtain County by Sheffield & Chapman (1992), for Pottawatomie County by Bradley et al. (1988), and for Osage and Payne counties by Thies et al. (1993). These records have extended the known range for this species considerably westward and southward than it previously was thought to be distributed. The first record for Okmulgee County is reported here and records are clarified for Rogers County. Caire et al. (1989) and Thies et al. (1993) questioned the final deposition of specimens from a Rogers County site; based on similarity of locality it is possible that the specimens in the MSB collection pertain to these specimens.

Material examined.—Okmulgee County: 1.0 mi S of Hoffman, Eufaula Wildlife Management Area, 1 specimen (TTU 62977); 3.0

mi E of Dewar, Eufaula Wildlife Management Area, 1 specimen (TTU 62976). Rogers County: 3.5 mi SW of Inola, T19N, R16E, Sec. 19, 1 specimen (MSB 113436); T19N, R16E, Sec. 19, 2 (MSB 113432, 113437); T19N, R16E, Sec. 24, 3 specimens (MSB 113430, 113431, 113434); T19N, R16E, Sec. 25, 1 specimen (MSB 113439).

Reithrodontomys megalotis

In Kansas, this species is found throughout the state (Bee et al. 1981) but in Texas, this species is known only from the Panhandle region (Schmidly 2002). The first record of the western harvest mouse for a county outside of the Oklahoma Panhandle and northwestern regions of Oklahoma was reported for Osage County by Payne & Caire (1999). This record represents a considerable eastward range extension. New records are reported for Murray and Washita counties, extending the range of this species into the south-central portion of the state.

Material examined.—Murray County: 2 mi S, 0.5 mi E of Davis, 1 specimen (TTU 38324). Washita County: 0.5 mi N of Canute, 1 specimen (CM 91432*).

Reithrodontomys montanus

The plains harvest mouse has a statewide distribution (Caire et al. 1989). This species was first reported for Caddo County by Stangl et al. (1992) and Smith (1992), for Greer County by Stangl et al. (1992), and for Texas County by Dalquest et al. (1990). New records are reported here for the counties of Grant, Kay, and Ottawa.

Material examined.—Grant County: 1.5 mi W, 1.4 mi N of Hawley, 1 specimen (OMNH 9145). Kay County: 5 mi S, 10.5 mi E of Newkirk, 1 specimen (OMNH 8733). Ottawa County: 2 mi N of Peoria, 1 specimen (KU 81948); 3 mi SW of Tri-State Monument, 1 specimen (KU 81878).

Erethizon dorsatum

Once considered uncommon in Oklahoma, the North American porcupine was thought to occur only from the Wichita Mountains westward into the Black Mesa region of Oklahoma (Caire et al. 1989). This large rodent has shown to be successful in an eastward expansion across the state (Tyler & Joles 1997; Tyler & Haynie 2001). A former sight record reported by Tyler & Haynie (2001) is here verified for Oklahoma County.

Material examined.—Oklahoma County: I-35 and 50th, 1 specimen (OMNH 29927).

Lepus californicus

The black-tailed jackrabbit is characteristic of western Oklahoma but has been reported from eastern counties as well. Clark & Tumilson (1992) reported the first observations of this species for Washita County. The first record is reported here for the southeastern county of McCurtain.

Material examined.—McCurtain County: 2.5 mi SW of Broken Bow, 1 specimen (TTU 4216).

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IDENTIFYING LANDSCAPES FOR DESERT BIGHORN SHEEP TRANSLOCATIONS IN TEXAS

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Abstract.—This study used a GIS-based evaluation of escape terrain to identify landscapes for potential desert bighorn sheep (*Ovis canadensis*) translocations sites in west Texas. The quantity and heterogeneity of escape terrain (i.e., slopes $\geq 60\%$ with a contiguous 150-m buffer) were quantified for Big Bend National Park, Guadalupe Mountains National Park, Big Bend Ranch State Park, and Black Gap Wildlife Management Area using a 30-m digital elevation model. Big Bend National Park had the largest amount of escape terrain (501 km²) of the four study areas but had the largest perimeter-to-area ratio (4.9). Guadalupe Mountains National Park had the smallest amount of escape terrain (112 km²) but also had the smallest perimeter-to-area ratio (2.8). Although other factors (e.g., vegetation, water availability, predators, and interspecific competitors) should be considered prior to translocation, the GIS-based evaluation offers an efficient, preliminary, and quantitative method for evaluating desert bighorn sheep habitat. Based on the results of this study, biologists should further evaluate Big Bend National Park and Big Bend Ranch State Park for future desert bighorn sheep translocation sites in Texas.

Historically, desert bighorn sheep (*Ovis canadensis*) occupied the rugged, mountainous terrain of west Texas (Cook 1994). Approximately 1,500 desert bighorn sheep were estimated to inhabit the Trans-Pecos ecoregion (Gould 1962) in the mid 1880s (Cook 1994). However, Bailey (1905) estimated the number of sheep in Texas had declined to 500 individuals by the beginning of the 20th century. Desert bighorn sheep continued to decline as a result of unregulated hunting, disease, interspecific competition (i.e., domestic sheep and goats), as well as predation, and by 1960, desert bighorn sheep were extirpated from Texas (Davis & Taylor 1939; Cook 1994).

Restoration efforts by the Texas Parks and Wildlife Department (TPWD) began in the mid 1950s, and although early efforts were of

limited success due to disease and predation (Krausman et al. 1999), more recent efforts (last 20-25 years) have been more successful. Currently, desert bighorn sheep have been restored to seven mountain ranges in the Trans-Pecos region and with a total population size exceeding 500 individuals (Brewer, pers. comm.).

Translocation is the management tool used by TPWD to establish desert bighorn sheep populations on public lands within historic range sites. However, current evaluation of desert bighorn sheep habitat prior to translocation is conducted through field observations. This is an inefficient method for evaluating the suitability of large landscapes for desert bighorn sheep restoration.

McKinney et al. (2003) hypothesized the size of desert bighorn sheep populations in Arizona were correlated to amount and configuration of escape terrain, and recommended translocation sites contain $\geq 15 \text{ km}^2$ of escape terrain. Escape terrain provides bedding and lambing areas, and is important in predator avoidance, therefore escape terrain is often considered the most critical component of bighorn sheep habitat (Buechner 1960; Ferrier & Bradley 1970; Geist 1971; Wilson et al. 1980). The use of geographic information system (GIS) technology provides an efficient, preliminary, and quantitative technique for evaluating habitat quality prior to desert bighorn sheep translocations (McKinney et al. 2003).

The goal of this study was to identify potential future translocation sites for desert bighorn sheep in Texas. The primary objective was to conduct a GIS-based evaluation of the quantity and heterogeneity of escape terrain for landscapes in the Trans-Pecos ecoregion of Texas. A second objective was to identify large blocks of potential habitat to serve as future re-introduction sites.

MATERIALS AND METHODS

Areas evaluated in this study were located in the Trans-Pecos ecoregion of west Texas. Big Bend National Park (BBNP), Big Bend Ranch State Park (BBRSP), and Black Gap Wildlife Management Area (BGWMA) are located in the southern portion of the Trans-

Pecos along the Rio Grande, an area often referred to as the Big Bend Area (Figure 1). Guadalupe Mountains National Park (GMNP) is located in the northern portion of the Trans-Pecos along the Texas/New Mexico border. All four study areas were evaluated for their potential as future desert bighorn sheep translocation sites. At the time of the study in 2004, BBNP, GMNP, and BBRSP did not contain desert bighorn sheep populations. Reintroduction efforts have occurred at BGWMA since the late 1950s with little success due to disease and predation (Cook 1994). Populations have since been established at BGWMA, and with the most recent translocation of 45 individuals (year 2000) current estimates range between 100-125 individuals (Foster, pers. comm.).

The Trans-Pecos is located within the Chihuahuan Desert. The study areas range in elevation from 475 m (above sea level) along the Rio Grande at BGWMA to 2,667 m at Guadalupe Peak in the Guadalupe Mountains (Powell 2000). Soils are of either igneous or limestone origin, and the climate is arid with an average annual rainfall of 30.5 cm with peak rainfall occurring between July and September (Powell 1998). The Trans-Pecos is biologically diverse and Powell (1998) categorized 5 broad vegetation types: Chihuahuan Desert scrub, desert grassland, oak/juniper/pinyon woodland, conifer forest, and riparian community.

Escape terrain area was calculated for all four study areas in a GIS using a 30-m resolution digital elevation model (Divine et al. 2000). Escape terrain was defined as slopes $\geq 60\%$ (Holl 1982; Smith et al. 1991; McCarty & Bailey 1994) with a contiguous 150-m buffer (McKinney et al. 2003). Elevations $\geq 1,600$ m and $\geq 2,200$ m at BBNP and GMNP, respectively were excluded from analysis due to the dense conifer forests supported in the upper elevations (Powell 1998). Desert bighorn sheep would likely not use these areas due to reduced visibility (Risenhoover & Bailey 1985; Wakeling 1989; Smith et al. 1991; McCarty & Bailey 1992; 1994). A ratio of perimeter (km) to area (km^2) of escape terrain (perimeter-to-area ratio, McKinney et al. 2003) was calculated to indicate a measure of patchiness or "edge effect" in the habitat (Singer et al. 2001).

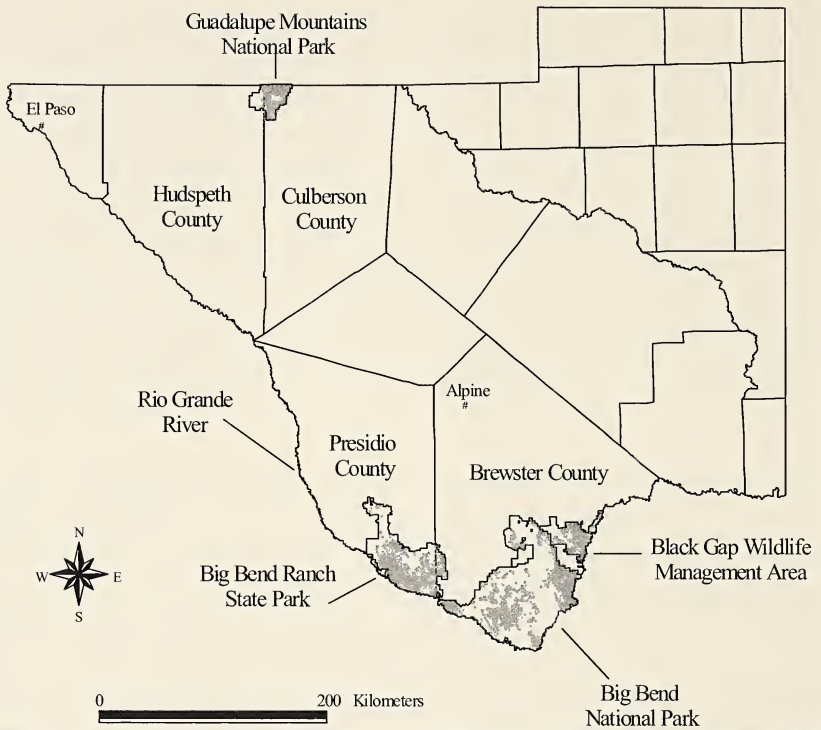


Figure 1. Location, area, and configuration of escape terrain (shaded gray) of four potential translocation sites for desert bighorn sheep in the Trans-Pecos ecoregion of Texas.

RESULTS AND DISCUSSION

Big Bend National Park had the largest amount of escape terrain (501 km^2) of the four study sites and the second largest perimeter-to-area ratio (4.9, Table 1, Figure 1). Big Bend Ranch State Park had the second largest amount of escape terrain (324 km^2) and the largest perimeter-to-area ratio (5.0). Black Gap Wildlife Management Area and GMNP had the third and fourth most escape terrain, respectively. Each of these study sites exceeded the minimum amount of escape terrain (15 km^2) recommended and the perimeter-to-area ratios were considerably smaller than those reported in Arizona (McKinney et al. 2003) suggesting escape terrain within the study areas was contiguous.

Table 1. Area and perimeter-to-area ratios of escape terrain located at Big Bend National Park (BBNP), Big Bend Ranch State Park (BBRSP), Black Gap Wildlife Management Area (BGWMA), and Guadalupe Mountains National Park (GMNP) in Texas.

StudyArea	Escape Terrain (km ²)	P:A [*]
BBNP	501	4.9
BBRSP	324	5.0
BGWMA	135	4.6
GMNP	112	2.8

^{*} P:A = perimeter (km) to area (km²) ratio of escape terrain.

Within numerous vertebrate species, population persistence has been positively correlated with habitat patch size (Fritz 1979; Schoerner & Spiller 1987; Thomas 1990; Fahrig & Merriman 1992; Kindvall & Ahlen 1992; Hanski 1994), and larger patches typically support larger populations (Gilpin & Soule 1986). Saunders et al. (1991) suggested larger patches contain more biological diversity and have lower perimeter-to-area ratios thus permitting greater genetic heterozygosity in wildlife populations. Singer et al. (2000a) recommended translocating bighorn sheep into large blocks of habitat with the potential for more than one subpopulation. Large blocks of habitat may allow ungulate populations to have larger ranges resulting in less overcrowding and improved body condition (Singer et al. 2001).

Theoretically, larger blocks of habitat may support larger bighorn sheep populations, and although there is some disagreement on the size of habitat needed for the persistence of desert bighorn sheep (Krausman & Leopold 1986; Krausman et al. 1993; Krausman et al. 1996), the goal in Texas is to establish large, self-sustaining desert bighorn sheep populations. Big Bend National Park, BBRSP, and BGWMA each have large amounts of escape terrain and relatively low perimeter-to-area ratios (≤ 5.0) suggesting

these three study sites consisted of relatively large habitat patches rather than patchy. In addition these three study sites share borders (Figure 1) thus increasing the total amount escape terrain or patch size and the ability to support > one subpopulation. Guadalupe Mountains National Park had the lowest perimeter-to-area ratio (2.8) but also had the least amount of escape terrain (112 km²). The GMNP is near the Sierra Diablo Mountains which contains established populations of desert bighorn sheep. However, barriers (e.g., highways, fencing) may preclude bighorn populations from interacting thereby isolating potential bighorn sheep populations in GMNP.

The GIS-based evaluation of escape terrain represents an efficient yet preliminary method for quantifying the amount of habitat prior to desert bighorn sheep translocations. However, translocations should not be based solely on the amount of escape terrain. Evaluations of other variables should be considered. For instance, permanent water sources should be mapped to determine availability. Adequate water sources should exist or be provided (e.g., man-made guzzlers) ≤ 8 km apart and within proximity to escape terrain (Douglas & Leslie 1999). Additionally, the composition and structure of vegetation communities is important to consider. Desert bighorn sheep are opportunistic and highly adaptable in regard to diet (Browning & Monson 1980; Brewer 2001), but prefer areas with high visibility (Risenhoover & Bailey 1985; Wakeling 1989; Krausman et al. 1999). Contact with domestic livestock and exotic sheep species (e.g., *Ammotragus lervia*) should be minimized or eliminated to prevent disease transmission, and interspecific competition (Douglas & Leslie 1999; Krausman et al. 1999; Singer et al. 2001). Predation can also be a limiting factor for translocated populations (Krausman et al. 1999), but predator management may allow populations time to be established. Finally, desert bighorn sheep contact with humans and human activities should be minimized especially during the rut and lambing seasons (Papouchis et al. 2001). Habitat should be free of natural (i.e., rivers, dense vegetation, and impassable canyons) and man-made barriers (i.e.,

fences, highways, and human constructions) to allow maximum mobility and genetic exchange among populations (Singer et al. 2000b).

Translocating desert bighorn sheep into historic range sites can be an effective management tool (Singer et al. 2000a), however translocations of large ungulates including desert bighorn sheep are expensive, time consuming, and politically challenging (Beck et al. 1994; Biggens & Thorne 1994; Wolf et al. 1996; Dunham 1997; Fritts et al. 1997). Furthermore, many transplanted herds of bighorn sheep have either remained small in numbers or subsequently failed (Risenhoover et al. 1988). Therefore, evaluating the area and configuration of escape terrain of potential re-introduction sites is a critical, yet preliminary step prior to translocation. McKinney et al. (2003) offers an efficient and quantitative GIS-based method for evaluating potential desert bighorn sheep re-introduction sites and may improve the potential for translocation success. Based on the results of this study TPWD biologists should further investigate BBNP and BBRSP as potential sites for future desert bighorn sheep translocations.

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DISTRIBUTION AND STATUS OF ARKANSAS RIVER SHINER
NOTROPIS GIRARDI AND RIO GRANDE SHINER *NOTROPIS*
JEMEZANUS, PECOS RIVER, NEW MEXICO

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Abstract.—Introduced Arkansas River shiner *Notropis girardi* and native Rio Grande shiner *Notropis jemezianus* coexist in the Pecos River, New Mexico, between Fort Sumner Irrigation District Dam and Brantley Reservoir. Both are pelagic, broadcast spawners. Sampling conducted between 1992 and 2002 found *N. girardi* composed 3.7% of all fish collected and *N. jemezianus* composed 10.7%. *Notropis girardi* appeared to be shorter lived than *N. jemezianus*. Age 0-1 individuals dominated populations of both species and had highest densities in downstream river stretches, presumably due to displacement of pelagic, semibouyant embryos and early larvae. *Notropis girardi* were less abundant in this study than in 1986 and 1987, when they were first discovered. During the presumed spawning season (May through August), *N. jemezianus* were most abundant in river stretches having less degraded river channel conditions - a wide channel with shifting sand substrate.

Arkansas River shiner *Notropis girardi* Hubbs & Ortenburger and Rio Grande shiner *Notropis jemezianus* (Cope) primarily inhabit medium and large rivers (Sublette et al. 1990; Cross & Collins 1995), only infrequently ascending small tributaries (Cross 1950; Treviño 1955; Hubbs et al. 1977; Cowley & Sublette 1987; Bestgen et al. 1989; Pittenger & Schiffmiller 1997). Both species are characteristic of main channel habitats of wide, open, sand laden rivers with variable flow regimes (Matthews & Hill 1980; Hatch et al. 1985; Polivka 1999). *Notropis girardi* is endemic to the Arkansas River drainage (Gilbert 1978a) while *N. jemezianus* is endemic to the Rio Grande drainage (Gilbert 1978b). The two species coexist in the Pecos River, New Mexico because *N. girardi* was accidentally introduced in 1978 (Bestgen et al. 1989). However, the rangewide distribution of both species has declined, so they are

each of conservation concern within their native ranges (Sublette et al. 1990; Hubbs et al. 1991; Wilde 2002).

Notropis girardi and *N. jemezianus* both broadcast nonadhesive semibuoyant eggs and spawn in spring and summer (Moore 1944; Cross 1950; Larson 1991; Platania & Altenbach 1998; Bonner 2000). Eggs normally hatch within 24 to 48 hours. Early larvae remain pelagic until the swim bladder and fins fully develop, usually in 48 to 72 hours. Thus, embryos and early larvae are highly susceptible to downstream displacement for 72 to 120 hours post spawning. However, this developmental rate is rapid compared to other fishes. Pelagic broadcast spawning is presumed advantageous in pristine floodplain rivers with unstable substrates because pelagic embryos and larvae have a low risk of burial and are readily distributed throughout habitats of wide, shallow river channels and floodplains that were typical of the pre-settlement Great Plains. Further, broadcasting eggs during high flows could be advantageous because habitat area is temporarily increased and flood intolerant animals (potential competitors and predators) are temporarily reduced.

The decline of *N. girardi* and *N. jemezianus* corresponded with human development of their native watersheds. Both species disappeared from river reaches that were dewatered or isolated by dams (Cross et al. 1985; Larson 1991; Platania 1991; Pittenger & Schiffmiller 1997; Bonner & Wilde 2000; Contreras-Balderas et al. 2002; Hoagstrom 2003). The Pecos River reach between Fort Sumner Irrigation District Dam and Brantley Reservoir (Fig. 1) harbors both of these species (Sublette et al. 1990). Sampling by seine was conducted throughout this river reach between 1992 and 2002 to monitor the federally threatened Pecos bluntnose shiner *Notropis simus pecosensis* (Gilbert & Chernoff) population (U.S. Fish and Wildlife Service 1987), providing an unprecedented record of *N. girardi* and *N. jemezianus* populations, which is summarized herein. In addition, a brief review of rangewide status is provided for both species.

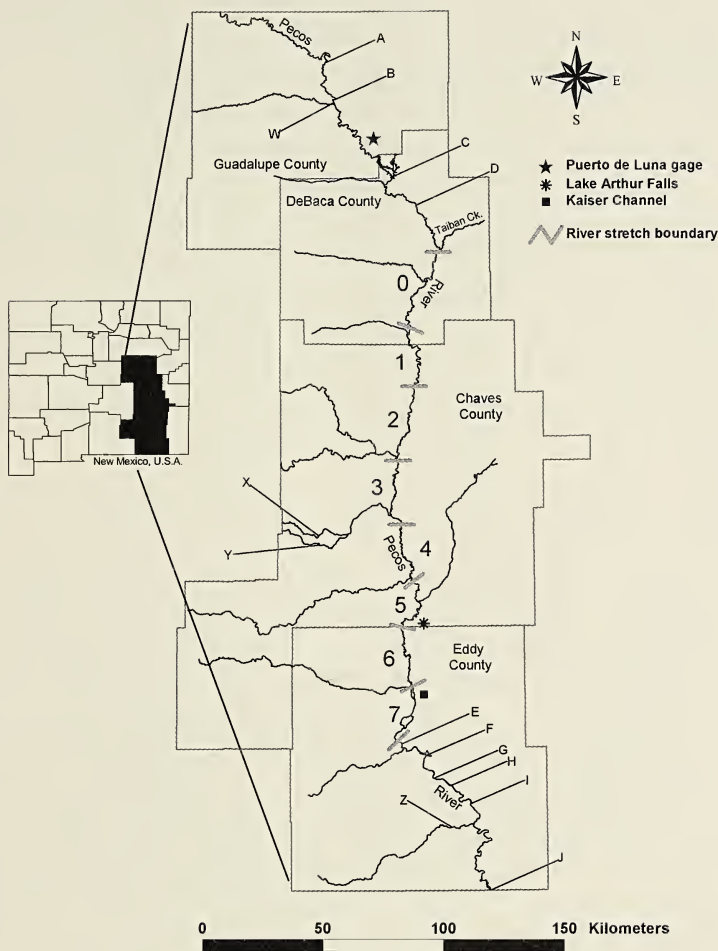


Figure 1. Location of study area and river stretches (numbered) along the Pecos River. Pecos River dams include Santa Rosa Dam (A), Puerto de Luna Dam (B), Sumner Dam (C), Fort Sumner Irrigation District Dam (D), Brantley Dam (E), Avalon Dam (F), Carlsbad Lakes and Dams (G), Sixmile Dam (H), Tenmile (Harroun) Dam (I), and Red Bluff Dam (J). Selected tributary dams include Agua Negra Dam (W), Diamond A Dam (X), Rocky Dam (Y), and Black River Dam (Z).

MATERIALS AND METHODS

The study area was the mainstem Pecos River from Fort Sumner Irrigation District Dam to Brantley Reservoir (Fig. 1), which drains

19,036 km² (U.S. Army Corps of Engineers 1991) of Rocky Mountain piedmont, vegetated by plains, mesa and desert grasslands (Dick-Peddie 1993). Average annual precipitation is 33 cm (Dick-Peddie 1993). This river reach has a highly modified flow regime due to dams and diversions upstream (Robertson 1997). Pecos River inflow, controlled by Sumner Dam, was 5.7 m³/s per year between 1937 and 2001 with 1.5 m³/s per year (26%) diverted at Fort Sumner Irrigation District Dam (Byrd et al. 2002). Hence, surface flows may fail during dry periods, particularly in spring, when the local climate is dry and snowmelt runoff from the upper watershed is captured by storage reservoirs upstream. As a result of the changed flow regime and channelization, the river channel has narrowed greatly (U.S. Army Corps of Engineers 1999).

Nevertheless, there are no dams or instream barriers between Fort Sumner Irrigation District Dam and Brantley Reservoir, the longest (335 km) undammed and unimpounded Pecos River reach in New Mexico. In addition, numerous uncontrolled tributaries issue periodic floods that buffer the effects of flow regulation by providing natural flood peaks and alluvial sediment inputs. Tributary base inflows and groundwater seepage provide base flow in some river stretches (Mower et al. 1964; Mourant & Shomaker 1970). Thus, the study area can be characterized as highly modified, but not as degraded as adjacent river reaches. During this study, the Pecos River had continuous surface flow from 1992 through 2001 because of frequent local rain and reservoir operations intended to maintain flow. Nonetheless, surface flow intermittence did occur at the end of the study, in spring and summer 2002.

For analysis of fish distributions, the study area was divided into river stretches (Fig. 1). These were intended to represent gradual longitudinal change in river channel conditions. Sumner Valley, extending from Fort Sumner Irrigation District Dam to Taiban Creek confluence (32 km), was a large alluvial valley used for irrigated croplands of the Fort Sumner Irrigation District. This stretch was sampled regularly throughout the study (Table 1). The

Table 1. Number of collections (*n*) and total area sampled (m²) for each river stretch by season.

River Stretch	January - April		May – August		September – December	
	<i>n</i>	m ²	<i>n</i>	m ²	<i>n</i>	m ²
Sumner						
Valley	23	5,339	34	9,187	29	7,206
0	3	1,052	5	1,378	4	1,107
1	37	10,623	36	10,394	41	12,481
2	43	12,915	42	12,867	44	13,771
3	42	11,396	50	12,751	51	12,683
4	25	7,194	35	9,594	37	9,134
5	23	6,012	24	5,558	23	5,600
6	20	5,403	18	4,205	23	5,192
7	23	5,339	29	6,460	32	6,908
Total	239	66,099	273	72,394	284	74,081

river channel in Sumner Valley was roughly 49 m wide, incised about 1.5 m, braided, and gravel armored. These conditions reflect impacts of Sumner Dam. The Sumner Valley stretch was de-watered by Sumner Dam and Fort Sumner Irrigation District Dam, but flow downstream was partly restored by irrigation returns. Substrates were gravel, changing to gravel-sand downstream, with mats of filamentous algae prevalent during summer low flow periods. Several substantial uncontrolled tributaries discharged floodwater and alluvial sediment in this stretch.

The Pecos River channel changed to a sand bed at Taiban Creek. Channel width increased to 59 m, channel incision remained at roughly 1.5 m, and the channel was braided. The sandy reach included river stretches 0, 1 and 2. The river channel gradually changed from upstream to downstream, narrowing to 33 m and incising to 2 m at the downstream end of stretch 2. Only limited collecting was done in river stretch 0 (44 km) because landowners only allowed access in 1992 and 1993 (Table 1). In contrast, river stretches 1 and 2 (both 39 km) were sampled regularly, throughout the study period (Table 1). Many uncontrolled tributaries joined the Pecos River in these stretches, contributing sediment and water.

Groundwater seepage supplemented base flow (Mourant & Shomaker 1970; Shomaker 1971). Habitat diversity within the Pecos River was high in all three stretches, with side channels, pools and backwaters being relatively abundant at base flow (Robertson 1997).

The Pecos River entered the Roswell Basin at the Salt Creek confluence. In the Roswell Basin, the river channel was only 28 m wide, incised 3.0 m, and confined to a single thread with hard packed silt-sand substrate. The Roswell Basin reach included river stretches 3, 4, 5, 6 (39 km each) and 7 (26 km). Each of these stretches was sampled regularly throughout the study (Table 1). The Roswell Basin reach was impacted by channelization and *Tamarix* infestation (Robinson 1965; Cox & Havens 1974). Groundwater seepage supplemented river flow (Mower et al. 1964), but habitat diversity was low at all flows with few side channels, backwaters or pools (Robertson 1997). River stretch 3 was most likely to lose surface flow because groundwater seepage there was depleted (Shomaker 1971). Few tributaries reached the river within the Roswell Basin and dams captured floods of western tributaries. River stretch 5 was unique because it included Lake Arthur Falls where a series of travertine outcrops created high habitat diversity (pools, backwaters, riffles) uncharacteristic of adjacent channelized stretches. River stretch 7 included only highly modified habitat: Kaiser Channel and Brantley Reservoir.

From February 1992 through October 2002, fish collections were routinely conducted among 47 study sites using a 3.2 mm mesh seine, 3.0 m long and 1.2 m deep. The length of each seine haul was measured to the nearest m. The area sampled was the product of seine haul length and seine width. Four to 8 seasonal sampling trips were made each year, depending upon river flows (collections bracketed high flow events). Eight to 14 sites were surveyed per trip. Sample sites varied among trips to increase river coverage and reduce collecting impacts at specific locations.

Seine collections were each completed within discrete, visually determined mesohabitats (sensu Gee & Northcote 1963; Armitage

et al. 1995; Vadas & Orth 1998). Following the hierarchical classification of Jackson (1975), a mesohabitat was an area with uniform water column characteristics; i.e., mean column velocity and water column depth was similar throughout. Sampling mesohabitats in proportion to their abundance was intended to representatively sample fish species (Matthews 1985; Taylor et al. 1996). Thus, 8 to 25 seine hauls were conducted among all available mesohabitats in proportion to their prevalence during each study site visit. As a result, more seine hauls were conducted when more mesohabitats were present.

Number of seine hauls per collection was also affected by fish capture efficiency. When Pecos River flow was very low, fishes were clumped in small pools because most of the river was very shallow. Thus, at these times, only a few seine hauls were necessary to collect a very large number of fishes and to representatively sample available mesohabitats. Clumped distributions of plains river fishes are not uncommon, particularly in times of low discharge or unfavorable water quality (Matthews & Hill 1980; Taylor et al. 1996). Further, sampling permit requirements precluded excessive sampling to limit collecting impacts on the federally threatened *N. simus pecosensis*.

Fish specimens were preserved in 10% formalin and later transferred to 70% ethanol. Specimens were identified, enumerated and measured to the nearest 0.01 mm standard length (SL) in the lab (not all specimens from 1992 and 1993 were measured). Specimens were deposited at the Museum of Southwestern Biology, University of New Mexico, Albuquerque.

Standard length (SL) graphs were prepared for all individuals measured of both species by trimester. Trimesters were January through April, May through August, and September through December. Second trimester (May through August) corresponds with the breeding season of *N. girardi* (Bestgen et al. 1989; Larson 1991; Bonner 2000) and presumably *N. jemezianus*. Thus, in first trimester, individuals were considered age 1 or older. The term age 0-1 refers to individuals in the same calendar year of their hatching. Age groups were estimated separately for each trimester, using the graphs.

Trends in abundance of each species and age group were qualitatively compared. Relative abundance (percent) of *N. girardi* and *N. jemezianus* was determined for each sample and averaged by river stretch. Density was calculated as the number of individuals collected per area seined (fish / m²). Density of each length group was calculated by collection and collection densities were averaged by trimester and river stretch.

RESULTS

A total of 796 fish collections were made. The number of collections by trimester was: 239 in January to April, 273 in May to August and 284 in September to December. Surveys were extensive in all river stretches and seasons except in river stretch 0 (Table 1). Sampling effort was greatest in river stretches 1, 2 and 3 because mesohabitats were more diverse there, requiring more seine hauls. Also, some survey trips were focused specifically on the status of the *N. simus pecosensis* populations in those river stretches.

Notropis girardi was present in 474 (59.5%) of the fish collections, representing 3.7 ± 7.0 SD % of all fish collected. The largest single collection was 1,361 individuals ($\bar{x}$ of *N. girardi* within all 796 collections = 11 ± 55 SD). In all, 7,014 *N. girardi* were captured. They ranged from 9.7 to 57.3 mm SL ($\bar{x}$ = 23.9 ± 6.9 SD mm SL). Overall, *N. girardi* had highest relative abundance in river stretches 0, 1 and 7 (Table 2). *Notropis girardi* density was highest between May and August, the spawning season (Tables 3, 4 and 5). Each age group was widely distributed among river stretches (Tables 3, 4 and 5). Age 0-1 *N. girardi* dominated the population between May and December (Fig. 2). Age 1 was dominant between January and April. Age 2+ was only found between January and August.

Notropis girardi was not evenly distributed among river stretches. Between May and December, Age 0-1 was much more dense than average in stretch 7 (Tables 3 & 4). Age 1 *N. girardi* were much more dense than average in river stretch 0 between May and August (Table 3), stretch 0 between September and December (Table 4), and stretch 1 between January and April (Table 5). Age 2+ was rare and restricted to river stretches 1, 2 and 3 (Tables 3 and 5).

Table 2. Summary of the *Notropis girardi* population by river stretch. Number of fish collections (*N*), number of individuals (*n*), mean relative abundance (%), and mean standard length (*SL*), each with standard deviation (*SD*) are given.

River Stretch	<i>N</i>	<i>n</i>	% ± <i>SD</i>		<i>SL</i> ± <i>SD</i> (mm)
Sumner Valley	106	76	0.6 ±	2.9	35.6 ± 8.1
0	13	142	11.3 ±	9.9	34.0 ± 5.3
1	132	1,786	5.2 ±	7.4	28.6 ± 6.8
2	110	1,622	3.8 ±	5.8	21.9 ± 6.9
3	143	969	3.5 ±	6.0	21.8 ± 4.7
4	97	410	2.1 ±	4.1	22.0 ± 4.2
5	70	646	2.9 ±	5.1	23.8 ± 4.9
6	61	194	3.2 ±	7.6	24.5 ± 3.6
7	84	1,169	4.3 ±	11.0	19.9 ± 4.4

Table 3. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis girardi* age group for the second trimester: May through August.

River stretch	Age 0-1				Age 1				Age 2+			
	Density (fish/100m ²)	Standard Length Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Standard Length Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Standard Length Min (mm)	Med (mm)	Max (mm)
Sumner Valley	1(<1)	18	18	21	2 (2)	30	40	49	0	-	-	-
0*	0	-	-	-	5 (5)	30	36	44	0	-	-	-
1	3(3)	11	24	29	3 (4)	29	35	44	0	-	-	-
2	17(40)	10	15	29	1 (1)	29	35	49	1(<1)	53	53	57
3	9(22)	11	19	29	1 (1)	29	34	44	0	-	-	-
4	2(2)	12	20	28	1 (1)	30	32	34	0	-	-	-
5	11(17)	10	22	29	3 (4)	29	33	47	0	-	-	-
6	2(2)	14	23	29	3	30	31	31	0	-	-	-
7	62(122)	11	18	29	3 (3)	29	33	41	0	-	-	-
Total	16(53)	10	18	29	2 (3)	29	34	49	1(<1)	53	53	57

* River stretch 0 data were from 1992 and 1993 only.

Table 4. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis girardi* age group for the third trimester: September through December.

River stretch	Age 0-1				Age 1				Age 2+			
	Density (fish/ 100m ²)	Standard Length			Density (fish/ 100m ²)	Standard Length			Density (fish/ 100m ²)	Standard Length		
		Min (mm)	Med (mm)	Max (mm)		Min (mm)	Med (mm)	Max (mm)		Min (mm)	Med (mm)	Max (mm)
Sumner Valley	1	-	31	-	0	-	-	-	0	-	-	-
0*	2(2)	23	34	35	5(6)	35	38	44	0	-	-	-
1	7(12)	12	24	35	1(1)	35	38	46	0	-	-	-
2	5(9)	11	23	35	1(1)	35	38	46	0	-	-	-
3	6(6)	11	21	35	1(<1)	36	39	42	0	-	-	-
4	5(5)	13	21	34	0	-	-	-	0	-	-	-
5	9(19)	13	23	31	<1	-	36	-	0	-	-	-
6	8(14)	17	23	35	0	-	-	-	0	-	-	-
7	12(15)	11	23	33	0	-	-	-	0	-	-	-
Total	6 (10)	11	23	35	1(2)	35	38	46	0	-	-	-

*River stretch 0 data were from 1992 and 1993 only.

Table 5. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis girardi* age group for the first trimester: January through April.

River stretch	Age 0-1				Age 1				Age 2+			
	Density (fish/ 100m ²)	Standard Length			Density (fish/ 100m ²)	Standard Length			Density (fish/ 100m ²)	Standard Length		
		Min (mm)	Med (mm)	Max (mm)		Min (mm)	Med (mm)	Max (mm)		Min (mm)	Med (mm)	Max (mm)
Sumner Valley	-	-	-	-	3 (3)	14	23	43	0	-	-	-
0*	-	-	-	-	9 (11)	18	29	39	0	-	-	-
1	-	-	-	-	12 (31)	18	30	44	2 (3)	45	47	55
2	-	-	-	-	5 (7)	11	23	45	<1(<1)	45	47	48
3	-	-	-	-	3 (4)	16	22	43	<1	-	46	-
4	-	-	-	-	2 (1)	17	22	33	0	-	-	-
5	-	-	-	-	9 (17)	16	26	36	0	-	-	-
6	-	-	-	-	8 (16)	17	26	34	0	-	-	-
7	-	-	-	-	8 (8)	14	23	43	0	-	-	-
Total	-	-	-	-	7 (17)	11	26	45	1(2)	45	47	55

^All fishes spawned the previous calendar year are considered age 1.

*River stretch 0 data were from 1992 and 1993 only.

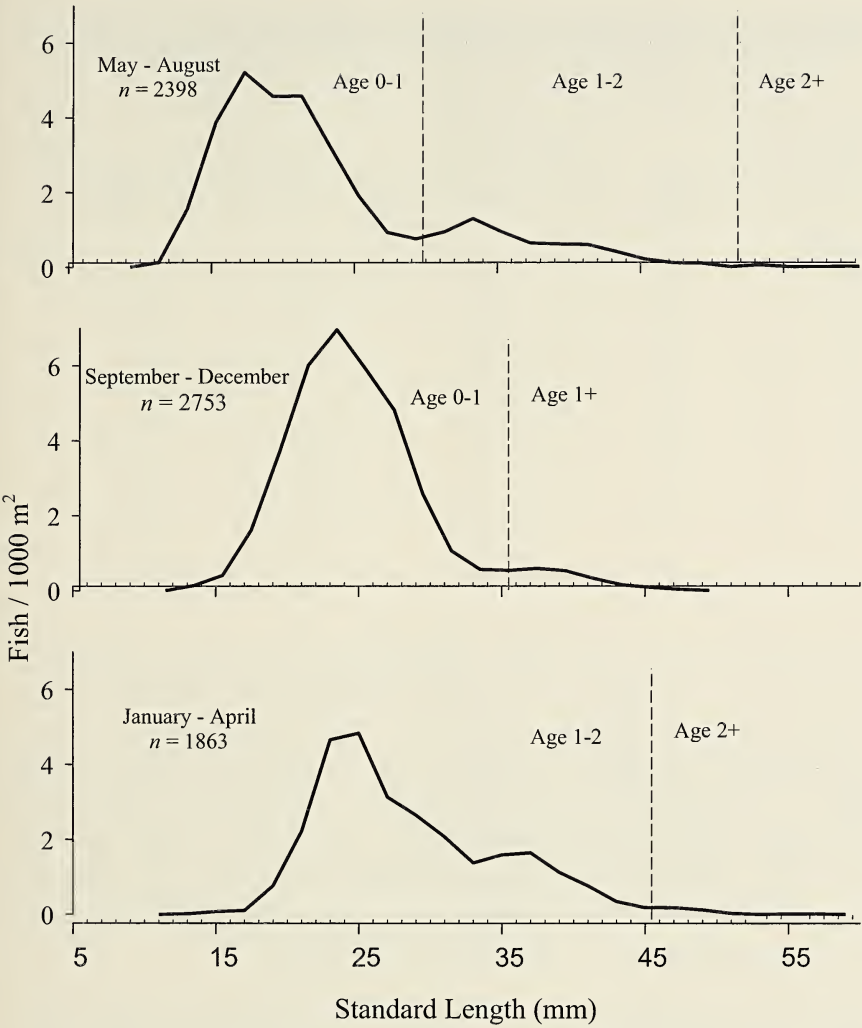


Figure 2. Standard length histograms (grouped into 2 mm categories) for *N. girardi* by trimester. Estimated age groups are indicated by vertical dashed lines.

Notropis girardi is extirpated from Arkansas and Colorado (Robison & Buchanan 1988; Fausch & Bestgen 1997) and has disappeared from most, if not all, of the Arkansas, North Canadian (Beaver) and Cimarron rivers in Kansas and Oklahoma (Cross &

Table 6. Summary of the *Notropis jemezianus* population by river stretch. Number of fish collections (N), number of individuals (n), mean relative abundance (%), and mean standard length (SL), each with standard deviation (SD) are given.

River Stretch	N	n	% $\pm$ SD		$SL \pm SD$ (mm)	
Sumner						
Valley	106	126	0.5 $\pm$	1.5	43.0 $\pm$	11.7
0	13	96	6.7 $\pm$	6.5	40.5 $\pm$	5.3
1	132	2,763	14.2 $\pm$	14.5	35.6 $\pm$	7.4
2	110	3,482	11.4 $\pm$	10.5	33.4 $\pm$	8.3
3	143	2,536	10.5 $\pm$	13.4	28.6 $\pm$	7.6
4	97	1,735	9.0 $\pm$	14.3	25.5 $\pm$	6.0
5	70	1,587	9.6 $\pm$	12.1	22.2 $\pm$	5.9
6	61	1,028	11.0 $\pm$	13.1	23.4 $\pm$	5.1
7	84	1,642	7.4 $\pm$	10.8	19.0 $\pm$	5.0

Collins 1995; Pigg et al. 1999; Wilde 2002). Further, it persists in only two river reaches of the South Canadian River drainage, New Mexico, Texas, and Oklahoma (Propst 1999; Wilde 2002) and these populations are declining (Larson 1991; Pigg et al. 1999; Wilde 2002). The nonnative Pecos River, New Mexico population was once more widespread (Bestgen et al. 1989), but *N. girardi* was absent from recent collections in the lower Pecos River (Hoagstrom 2003) and the Rio Felix (Table 10). Thus, the Pecos River *N. girardi* population was confined to the study area.

Notropis jemezianus was present in 659 (82.8%) of the fish collections, representing 10.7 ± 13.0 SD % of all fish collected. The largest single collection was 474 individuals ($\bar{x}$ of *N. jemezianus* within all 796 collections = 20 ± 35 SD). A total of 15,034 *N. jemezianus* was collected. *Notropis jemezianus* density was high between May and December and less between January and April (Tables 7, 8 and 9). *Notropis jemezianus* had high relative abundance in river stretches 1 through 6, being most prevalent in river stretch 1 (Table 6). *Notropis jemezianus* specimens were between 8.5 and 70.5 mm SL ($\bar{x}$ = 28.8 ± 9.2 SD mm). Each length

Table 7. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis jemezanus* age group for the second trimester: May through August.

River stretch	Age 0-1				Age 1				Age 2+			
	Standard Length				Standard Length				Standard Length			
	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)
Sumner Valley	1 (1)	9	9	31	1 (2)	34	42	48	2 (2)	49	51	61
0*	<1(<1)	26	27	29	6 (4)	32	39	47	1(<1)	48	50	51
1	3 (6)	13	26	32	7 (7)	32	39	48	1(1)	48	51	66
2	4 (5)	13	35	32	5 (6)	32	38	48	1(1)	48	51	69
3	6 (8)	12	22	32	3 (5)	32	40	48	1(<1)	48	50	66
4	3 (4)	12	21	32	1(<1)	32	39	46	1(<1)	49	51	56
5	10 (15)	10	20	31	1(<1)	32	36	44	<1(<1)	53	53	53
6	12 (21)	13	22	31	<1(<1)	33	38	44	<1	-	49	-
7	38 (74)	10	16	30	0	-	-	-	0	-	-	-
Total	9 (29)	10	18	29	4(5)	29	34	49	2(2)	53	53	57

*River stretch 0 data were from 1992 and 1993 only.

group was widely distributed among river stretches (Tables 7, 8 and 9). Age 0-1 *N. jemezanus* dominated the population between May and December, with age 1 dominant between January and April (Fig. 3). Age 1 was also abundant between May and August, but less abundant between September and December. Age 2+ was uncommon, but present in all trimesters.

Within the study area, *N. jemezanus* distribution and abundance were variable by age group and season. Age 0-1 was much denser than average in stretch 7 between May and August but more evenly between September and December (Tables 7 and 8). Age 1 *N. jemezanus* were most dense in river stretch 1 between May and August (Table 7) and stretch 3 between January and April (Table 9). Age 2+ had generally low density.

Notropis jemezanus was also found at one locality in a Pecos River tributary within the study area (Table 10). In all, 39 speci-

Table 8. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis jemezanus* age group for the third trimester: September through December.

River stretch	Age 0-1				Age 1				Age 2+			
	Standard Length				Standard Length				Standard Length			
	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)
Sumner Valley	1(<1)	16	35	40	2	43	47	52	1	55	57	60
0*	2(<1)	31	40	42	2(<1)	42	47	52	0	-	-	-
1	8(8)	16	32	42	2(4)	42	45	54	1(1)	55	56	61
2	10(12)	15	29	42	2(1)	42	45	53	<1(<1)	54	56	62
3	8(8)	11	26	42	1(1)	42	44	53	1(1)	54	55	58
4	13(11)	12	25	42	1(1)	42	44	51	1(<1)	55	56	56
5	16(17)	9	21	40	<1(<1)	44	44	51	<1	-	60	-
6	15(15)	11	24	40	1(1)	44	46	49	<1	-	56	-
7	15(24)	11	21	38	<1	-	45	-	0	-	-	-
Total	11(13)	9	26	42	2(3)	42	45	54	1(1)	54	56	62

*River stretch 0 data were from 1992 and 1993 only.

mens were collected during 1 of 4 collections from the Rio Hondo, roughly 2 km upstream from river stretch 3. These individuals were between 25.6 and 33.5 mm SL ($\bar{x}$ = 29.6 ± 2.1 SD mm SL).

Notropis jemezanus has disappeared from the Rio Grande upstream of the Rio Conchos confluence, New Mexico, Texas, and Chihuahua (Bestgen & Platania 1990; Platania 1991), the Rio Grande downstream from Falcon Reservoir, Texas and Tamaulipas (Edwards & Contreras-Balderas 1991; Contreras-Balderas et al. 2002), the lower Pecos River, New Mexico and Texas (Hoagstrom 2003), including Independence Creek (Bonner et al. 2005) and portions of the Rio Conchos, Chihuahua (Edwards et al. 2002a; 2002b; 2003). *Notropis jemezanus* once occupied the Rio Salado and Rio San Juan, Coahuila, Nuevo Leon, and Tamaulipas (Guerra 1952; Gilbert 1978b), but the recent status of the species there is unknown. Aside from the Pecos River between Fort Sumner Irrigation District Dam and Brantley Dam, New Mexico, *N. jemezanus*

Table 9. Mean density (with standard deviation) and length range (minimum, median, and maximum standard length) of each *Notropis jemezanus* age group for the first trimester: January through April.

River stretch	Age 0 [^] -1				Age 1				Age 2+			
	Standard Length				Standard Length				Standard Length			
	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)	Density (fish/100m ²)	Min (mm)	Med (mm)	Max (mm)
Sumner Valley	-	-	-	-	3(5)	31	40	46	2(2)	46	52	60
0*	-	-	-	-	1(1)	26	41	43	1	-	48	-
1	-	-	-	-	10(12)	13	32	46	1(1)	46	51	62
2	-	-	-	-	10(10)	12	31	46	2(3)	46	50	69
3	-	-	-	-	11(12)	13	29	46	1(1)	46	50	71
4	-	-	-	-	7(9)	14	27	46	<1(<1)	46	48	51
5	-	-	-	-	6(9)	12	26	43	<1	59	-	-
6	-	-	-	-	4(5)	10	21	45	0	-	-	-
7	-	-	-	-	2(2)	17	23	45	1	61	64	67
Total	-	-	-	-	8(10)	10	29	46	1(2)	46	50	71

[^]All fishes spawned the previous calendar year are considered age 1.
*River stretch 0 data were from 1992 and 1993 only.

persists in certain Rio Conchos watershed localities, Chihuahua (Edwards et al. 2002a; 2002b; 2003) and the Rio Grande from the Rio Conchos confluence to Falcon Reservoir, Chihuahua, Coahuila, and Texas (Edwards et al. 2002a; 2002b; 2003; Garrett 2002; Moring 2002).

DISCUSSION

Both *N. girardi* and *N. jemezanus* were common in the Pecos River between Taiban Creek confluence and Brantley Reservoir (river stretches 0 through 7) from 1992 through 2002. Introduced *N. girardi* has persisted for 25 years, but was less prevalent during this study than in 1986 and 1987 (Bestgen et al. 1989). Further, *N. girardi* was less prominent in the Pecos River than historically in its native range (Cross 1950; Matthews & Hill 1980; Pigg et al. 1999; Bonner & Wilde 2000). Reasons why *N. girardi* never gained the level of prominence in the Pecos River as in the Arkansas River

Table 10. Number of *N. girardi* and *N. jemezianus* collected in 1992 to 2002 surveys upstream from the study area either in tributaries or in the Pecos River mainstem. The number of study sites and number of collections (site visits) for each stream reach are also given.

River Reach	Sites	Collections	<i>Notropis girardi</i>	<i>Notropis jemezianus</i>
Pecos River, South San Ysidro to Gallinas River confluence	7	28	0	0
Pecos River, Gallinas River confluence to Santa Rosa Dam	1	9	0	0
Pecos River, Santa Rosa Dam to Puerto de Luna Dam	3	16	0	0
Pecos River, Puerto de Luna Dam to Sumner Dam	3	31	0	0
Pecos River, Sumner Dam to Fort Sumner Irrigation District Dam	1	20	0	0
Salt Creek, 2.5 km upstream of Pecos River, river stretch 2	1	4	0	0
Bob Crosby Draw, 3.0 km upstream of Pecos River, river stretch 2	1	1	0	0
Rio Hondo, 2.0 km upstream of Pecos River, river stretch 3	1	4	0	39
Rio Felix 2.0 km upstream of Pecos River, river stretch 4	1	4	0	0

basin are unidentified. Perhaps the presence of *N. jemezianus*, *N. simus pecosensis* and *Notropis stramineus stramineus* (Cope) in the Pecos River was partly responsible. In its native range, *N. girardi* usually only coexists with two or fewer abundant (> 1.0% of fish community) congeners (Cross 1950; Matthews & Hill 1980; Pigg 1987; Larson 1991; Bonner & Wilde 2000). Further, introduction of a closely related congener (*N. bairdi*) to the Cimarron River corresponded with the decline of *N. girardi* (Felley & Cothran 1981; Cross et al. 1983). However, *N. girardi* is also susceptible to high water temperatures (Matthews & Maness 1979) and regulated flow regimes (Cross et al. 1985; Larson 1991; Bonner & Wilde 2000).

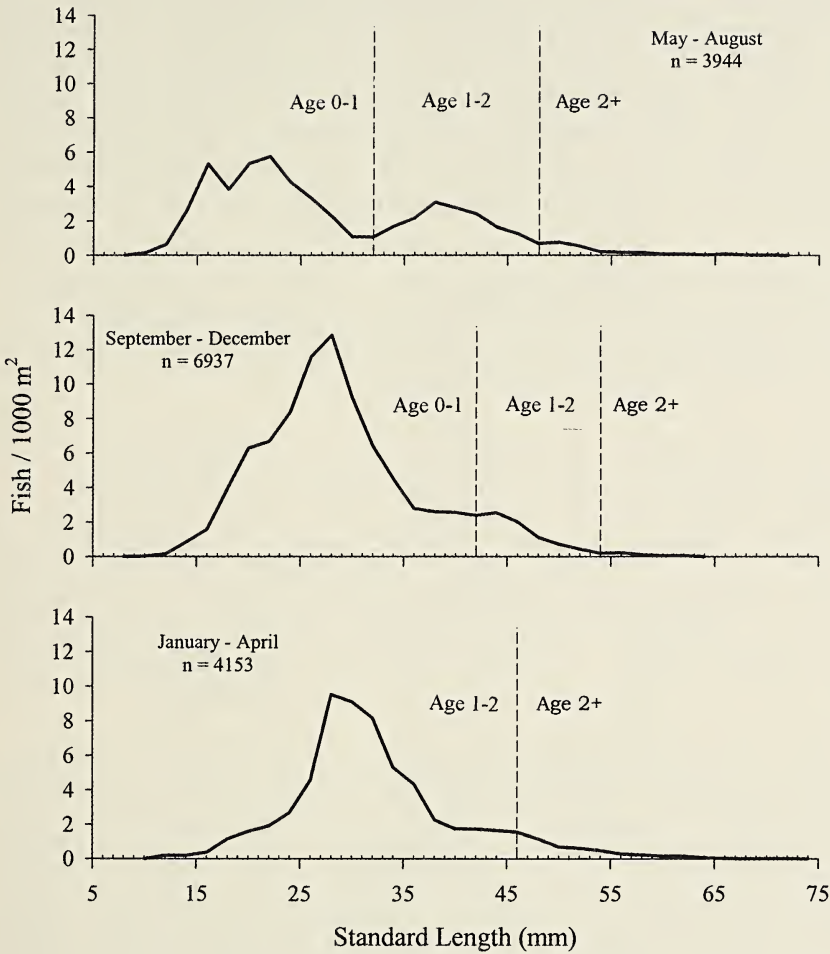


Figure 3. Standard length histograms (grouped into 2 mm categories) for *N. jemezianus* by trimester. Estimated age groups are indicated by vertical dashed lines.

Further, the species uses a wide range of habitat types throughout life (Polivka 1999). So, it is possible that habitat features of the Pecos River limit *N. girardi* abundance.

The Pecos River between Fort Sumner Irrigation District Dam and Brantley Reservoir harbors the largest known *N. jemezianus* population. This is also the last remaining population within the Pecos River basin (Bestgen & Platania 1990; Hoagstrom 2003; Bonner et al. 2005). However, *N. jemezianus* populations elsewhere are less well studied. Although long term stability of the Pecos River population was encouraging, decline of the species overall (Bestgen & Platania 1990; Edwards et al. 2002a; 2002b; Hoagstrom 2003) combined with drought conditions and water withdrawals throughout the Rio Grande basin (Mace et al. 2001; Scudday 2003; Sharp et al. 2003) suggest that all *N. jemezianus* populations should be frequently monitored and considered for protection.

Population trends varied between *N. girardi* and *N. jemezianus*. *Notropis jemezianus* was more abundant than *N. girardi* and age 1 *N. jemezianus* were more prevalent than age 1 *N. girardi*. Disappearance of age 2+ *N. girardi* after August was consistent with findings of previous researchers who concluded that the majority of the annual spawning population was age 1 (Cross et al. 1985; Bestgen et al. 1989; Bonner 2000). *Notropis jemezianus* were apparently longer lived, with more individuals surviving at least two winters.

There was a lower limit to the length of *N. girardi* and *N. jemezianus* that were captured efficiently with a 3.2 mm mesh seine. Based on the abundance of individuals in collections (Figs. 2 and 3), capture efficiency declined with SL for individuals < 16.0 mm SL. Collections of very small (< 12.0 mm SL) individuals likely were made only under fortuitous circumstances such as high fish density, when fishes were clumped together and less likely to fall through the seine mesh before they were gathered. Thus, abundance of age 0-1 *N. girardi* and *N. jemezianus* was certainly underestimated. Age 0-1 individuals of both species were found in each river stretch, indicating that recruitment took place throughout the study area. Wide distribution of age 0-1 *N. girardi* and *N. jemezianus* illustrated the ability of these pelagic, broadcast spawners to, at least temporarily, populate large areas, presumably by passive embryo and larva transport (Moore 1944; Cross et al. 1955; 1985). The reasons for low density of older *N. jemezianus* in downstream river stretches are unclear. Several authors

have advanced the hypothesis that pelagic embryos and larvae displaced downstream eventually return upstream as juveniles or adults, to maintain spawning populations (Cross et al. 1985; Fausch & Bestgen 1997; Platania & Altenbach 1998; Bonner 2000). However, this hypothesis has not been tested. It is also possible that differences in river channel conditions between downstream and upstream river stretches correspond with recruitment, growth and survival of *N. jemezianus*.

High abundances of age 0-1 fish downstream of spawning areas is not unique to pelagic spawning minnows. Fish larvae and juveniles of many species are susceptible to downstream displacement (Gerlach & Kahnle 1981; Brown & Armstrong 1985; Harvey 1987) and may have skewed distributions as a result (Peterson & VanderKooy 1995; Scheidegger & Bain 1995). However, the fate of displaced fish larvae and small juveniles has rarely been studied (but see Elliott 1986). Whether displaced *N. girardi* and *N. jemezianus* eventually join upstream populations via dispersal or whether upstream populations are maintained by embryos and larvae that are not displaced, i.e., those that recruit within upstream river stretches, is unknown and is a subject for further study.

River stretches 0 through 2 had a wide river channel with a loose, shifting sand substrate that maintained high habitat diversity, including side channels, pools and backwaters that were rare downstream (Robertson 1997). Age 1 *N. jemezianus* were abundant in these less degraded stretches in May through August, presumably the spawning season. Geomorphic conditions of stretches 0 through 2 were most similar to those prevailing throughout the historical range of *N. jemezianus* prior to human modifications (for descriptions see Hoagstrom 2003; Schmidt et al. 2003). Thus, it is not surprising that these river stretches are favored for *N. jemezianus* spawning. The combination of uncontrolled tributary inflows, groundwater seepage inflows, unstable sand substrate and absence of instream barriers make this river section unique, not only within the Pecos River, New Mexico, but throughout the modern day Rio Grande watershed. This river section appears less degraded and, so long as surface flow is continuous through the study area, fishes have unobstructed access to the less degraded section from many km downstream.

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PARASITE ASSEMBLAGES IN CENTRARCHID FISHES FROM BACKWATER HABITATS IN SOUTHEAST TEXAS, U.S.A.

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Abstract.—Between March, 2001 and August, 2002, 56 fishes representing nine species from the family Centrarchidae were collected from three backwater habitats in Hardin County, Texas, U.S.A. Hosts were examined for endoparasites and ectoparasites. Fifty-two fish (93%) were infected with one or more parasites. A total of 9300 parasite individuals representing five phyla were collected. These included Acanthocephala, Arthropoda (Copepoda), Platyhelminthes (Cestoidea, Trematoda, Monogenea), Nematoda, and Mollusca (glochidia larvae). The mean abundance of infection was 166.07 ± 178.18 parasites per host individual. The metacercarial stage of the trematode *Posthodiplostomum minimum* occurred with highest prevalence and mean abundance.

Although surveys of the parasites of centrarchid fishes abound in the literature, relatively few have been conducted in Texas (Sparks 1951; Allison & McGraw 1967; Lawrence & Murphy 1967; McGraw & Allison 1967; Meade & Bedinger 1967, 1972; Underwood 1975; Gruninger et al. 1977; Ingham & Dronen 1980; Underwood & Dronen 1984) and, to the authors' knowledge, none have been conducted in the backwater habitats of southeast Texas. This report presents the results of a survey of the macroparasites of nine species of centrarchid fishes collected from three such habitats.

METHODS AND MATERIAL

Fish were collected from three backwater habitats in the Neches River Basin of southeast Texas. The collection sites (Massey Lake, Maple Slough, and Caney Slough) were all located in Hardin County, Texas. All three aquatic habitats are eutrophic with little to no littoral zone and are hypoxic for a portion of the year. Massey Lake (30°17'N, 94°10'W) is a flood plain lake formed by an abandoned channel of Village Creek (Marsh 1973). Host collections from the Maple Slough (30°30'N, 94°07'W) site were made from two oxbows along the slough located within the Jack Gore Baygall

unit of the Big Thicket National Preserve. Caney Slough (30°15'N, 94°10'W) is a narrow stream connecting with Village Creek, and located within Village Creek State Park. Fish were collected between 9 March 2001 and 7 August 2002 using flag nets, Fike nets, and fish traps. Fish were then placed on ice and transported to the laboratory where they were labeled and frozen. Host necropsies were performed as time permitted. External surfaces, internal organs, and body cavity were examined for parasites. All parasites were preserved, stained, when necessary, and mounted for identification using standard techniques.

A total of 56 fish representing nine species and three genera were collected, including: 23 *Lepomis macrochirus* (bluegill sunfish), 16 *Lepomis megalotis* (longear sunfish), five *Lepomis gulosus* (warmouth sunfish), two *Lepomis punctatus* (spotted sunfish), one *Lepomis marginatus* (dollar sunfish), three *Pomoxis annularis* (white crappie), one *Pomoxis nigromaculatus* (black crappie), one *Micropterus salmoides* (largemouth bass), and one *Micropterus punctulatus* (spotted bass). Additionally, three juvenile sunfish were collected that were identified as *Lepomis* sp.

RESULTS

Necropsies revealed that 52 of 56 (93%) fish were infected with one or more parasites. Overall abundance of infection was 166.07 ± 178.18 parasites per host. A total of 9300 parasite individuals representing five phyla were collected. Infection data for all host and parasite species are presented in Table 1. Voucher specimens were sent to the Harold W. Manter Laboratory, University of Nebraska State Museum (HWML numbers 45772-45786). This study represents the first report of several parasite species from their respective hosts in Texas (Table 1).

The parasite that occurred in the greatest number of hosts (84%) and with the greatest abundance (147.84 ± 170.37 , range = 0-596) was the neascus metacercaria of the trematode *Posthodiplostomum*

minimum. It occurred in the parenchyma of several organs throughout the body as well as the coelom and mesenteries. Other trematodes recovered were the diplostomula of *Diplostomum spathaceum* occurring in the eyes of *L. macrochirus* and *L. gulosus*, and *Pisciamphistoma* sp. from the intestines of the same two host species. Plerocercoids of the tapeworm *Proteocephalus* sp. were collected from *L. macrochirus*, *L. megalotis*, and *L. punctatus*.

Fifty-two percent of the fish hosts were infected with a total of 757 monogenetic trematodes representing four genera: *Oncholeidus*, *Haploocleidus*, *Cleidodiscus*, and *Pterocleidus*. The only host species conclusively determined to harbor all four monogeneans were *L. macrochirus* and *M. salmoides*. None of the *Pomoxis* sp. harbored monogeneans. Most of the monogenea were minute and difficult to work with following host freezing. Consequently, species level identification was not attempted. It was also impossible to identify each monogenean individual to genus. Therefore, prevalence and abundance values were not calculated for individual monogenean genera from each host species.

At least two species of acanthocephala were collected. *Neochinorhynchus cylindratus* occurred in *L. megalotis*, *M. salmoides*, and *M. punctulatus*. Acanthocephala belonging to the family Echinorhynchidae were recovered from a broader range of host species. Numbers of cement glands present in the male specimens could not be determined, so genus-level identification was not attempted. Cystacanth larvae were recovered from two of the three immature *Lepomis* sp. Only fish collected from Caney Slough were infected with acanthocephala.

Juvenile nematodes occurred in several hosts. Individuals of *Contracaecum* sp. were recovered from the alimentary canal of *P. annularis* and both *Micropterus* sp. Additionally several hosts harbored encysted or free nematode juveniles which could not be identified.

Table 1. Location of infection, % prevalence, mean abundance $\pm$ standard deviation, and range (in parentheses) of infection of parasites from centrarchid hosts. New host records for Texas are also noted.

Parasite taxon	Location	Host species										
		<i>L. macrochirus</i>	<i>L. megalotis</i>	<i>L. gulosus</i>	<i>L. punctatus</i>	<i>L. marginalis</i>	<i>Lepomis</i> sp.	<i>P. annulatus</i>	<i>P. nigromaculatus</i>	<i>M. salmoides</i>	<i>M. punctulatus</i>	All Centrarchids
Platyhelminthes		n=23	n=16	n=5	n=2	n=1	n=3	n=3	n=1	n=1	n=1	n=56
Digenaea												
<i>Posthodiplostomum minimum</i> *	VO,OM†	91% 251.39±184.25 (0-596)	88% 101.81±135.18 (0-454)	80% 24.60±22.53 (0-54)	100% 239.50±190.21 (105-374)	100%± 35	100% 10.33±5.03 (5-15)	-	-	100% 135	100% 65	84% 147.84±170.37 (0-596)
<i>Diplostomum spathaceum</i> *	E	13%± 0.35±1.11 (0-5)	-	20%± 0.40±0.89 (0-2)	-	-	-	-	-	-	-	7% 0.18±0.77 (0-5)
<i>Pisciamphtisoma</i> sp. I	I	4% 0.04±0.21 (0-1)	-	20%± 0.20±0.45 (0-1)	-	-	-	-	-	-	-	4% 0.04±0.20 (0-1)
Monogenea												
Ancyrocephalidae	G	74% 18.30±22.14 (0-77)	31% 2.19±4.97 (0-19)	40% 6.0±10.39 (0-24)	50% 9.00±12.73 (0-18)	100% 11	33% 5.00±8.66 (0-15)	-	-	100% 220	100% 7	52% 13.52±32.60 (0-220)
Cestoidea												
<i>Proteocephalus</i> sp. * OM		9% 0.30±1.26 (0-6)	6% 0.06±0.25 (0-1)	-	50%± 1.50±2.12 (0-3)	-	-	-	-	-	-	7% 0.20±0.90 (0-6)
Acanthocephala												
<i>Neochinomyrchus cylindriatus</i>	I	-	6% 0.13±0.50 (0-2)	-	-	-	-	-	-	100% 21	100% 5	5% 0.50±2.88 (0-21)

Echinorhynchidae	I	4% 0.35±1.67 (0-8)	19% 1.31±4.25 (0-17)	-	50% 1.00±1.41 (0-2)	-	67% 3.33±4.93 (0-9)	-	100% 1	-	14% 0.75±2.76 (0-17)
cystacanth *	OM	-	-	-	-	-	67% 3.00±3.00 (0-6)	-	-	-	4% 0.16±0.89 (0-6)
Nematoda											
Contracaecum sp.*	I,Es,S	-	-	-	-	-	-	33% 0.33±0.58 (0-1)	100% 1	100% 2	5% 0.07±0.30 (0-2)
Uncysted larvae*	E,G,I,BC	-	6% 0.06±0.25 (0-1)	-	-	-	-	33% 0.33±0.58 (0-1)	100% 53	-	5% 0.96±7.08 (0-53)
Encysted larvae*	OM	4% 0.13±0.63 (0-3)	6% \$ \$	20% 0.40±0.89 (0-2)	-	-	33% 0.33±0.58 (0-1)	100% 23	-	11% 34	1.15±5.49 (0-34)
Arthropoda											
Copepoda											
Erigasilus caeruleus	G	22% 0.61±1.56 (0-7)	19% 0.63±1.41 (0-4)	-	50% 0.50±0.71 (0-1)	-	33% 0.33±0.58 (0-1)	-	-	-	18% 0.46±1.26 (0-7)
Achtheres sp.	G	-	-	-	50% 0.50±0.71 (0-1)	-	-	-	-	-	2% 0.02±0.13 (0-1)
Mollusca											
Bivalvia											
Glochidia *	G	4% 0.04±0.21 (0-1)	6% 0.50±2.00 (0-8)	-	50% 1.50±2.12 (0-3)	-	-	100% 1	-	-	7% 0.23±1.14 (0-8)

*larval stage
† BC = body cavity, E=eye, Es=esophagus, G=gill, I = intestine, OM = organ mesentery, S=stomach, VO = various organs.
‡ New host record for this host in Texas
\$ too numerous to count accurately.

The parasitic copepod *Ergasilus caeruleus* occurred in low abundance on the gills of 18 percent of the host fish, and a single *Achtheres* sp. occurred on the gills of one of the *L. punctatus*. The gills of seven percent of the hosts were infected with small numbers of glochidia clam larvae.

CONCLUSIONS

The component parasite communities in these locations were taxonomically diverse, including at least 16 species representing five phyla and several life history strategies. It is therefore difficult to isolate any single factor as most important in structuring these communities. The parasite that occurred with highest prevalence and abundance was *P. minimum*, which has a complex life cycle, utilizing snails and fish as first and second intermediate hosts, and herons as definitive hosts. It can therefore be categorized as allogenic: a parasite using aquatic vertebrates as intermediate hosts and completing its life cycle in birds or mammals (Esch et al. 1988). Of the parasites identified to at least family, only two others were allogenic and both occurred with low prevalence and abundance. *Contracaecum* sp. matures in a variety of birds and mammals, and *Diplostomum spathaceum* matures in birds. All other indirect life cycle parasites were autogenic: complete their life cycles within aquatic hosts (Esch et al. 1988). These include *Pisciamphistoma* sp., *Proteocephalus* sp., the Acanthocephala, and glochidia larvae. The existence of so many indirect life cycle species indicates that food web interactions are important in structuring parasite communities of centrarchid fishes from these locations. However, the parasites occurring with second highest prevalence and abundance were the combined monogenes. These as well as the copepods have direct life cycles, functioning independently of host trophic interactions.

Southern backwater habitats like those of this study have received little attention in terms of their parasite communities. They differ extensively in their limnological characteristics from

the lakes where most ecological studies of fish parasites have been conducted in the United States. Further study of parasite communities in these habitats is certainly needed.

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A QUANTITATIVE TECHNIQUE FOR DETERMINING NEST-SITE FIDELITY IN EASTERN WILD TURKEYS USING RADIOTELEMETRY DATA

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Abstract.—Nest-site fidelity has long been recognized in many bird species. Criteria for determining nest site fidelity, however, have varied among studies and often is subjective. Problems associated with these methods include difficulty in determining a distance or area which defines nest-site fidelity. Moreover, by using these methods, the observed “fidelity” may be a result of limited nest sites. A method of determining nest-site fidelity that is quantitative and considers available nesting habitat is described in this study. Radiotelemetry data on eastern wild turkeys (*Meleagris gallopavo silvestris*) are used to illustrate the technique.

Resumen.—La fidelidad de anidar se ha reconocido en muchas especies de pájaros. Los criterios para determinar la fidelidad del sitio nidal, sin embargo, han variado entre estudios y han sido a menudo subjetivos. Los problemas asociados con estos métodos incluyen la dificultad en determinar una distancia o un área que define la fidelidad de anidar. Por otra parte, al usar estos métodos, la “fidelidad observada” puede ser el resultado de una limitación de sitios para anidar. En este estudio, describimos un método para determinar la fidelidad de anidar que es cuantitativa y considera el habitat disponible para anidar. Los datos de radiotelemetría sobre los pavos silvestres (*Meleagris gallopavo silvestris*) se utilizan para ilustrar la técnica.

Nest-site fidelity has long been recognized for many migratory (Gauthier 1990; Reed & Oring 1993) and nonmigratory (Ingold 1991; Jenkins & Jackman 1993) birds. Nest-site fidelity is defined as the tendency for females to return to the same area or use of the same nest bowl in subsequent years (Bergerud & Gratson 1988). The behavior of nest-site fidelity is considered to be beneficial for nesting birds because (1) area familiarity decreases predation risk and (2) the likelihood of success is enhanced due to previous nest success (Bergerud & Gratson 1988; Hepp & Kennamer 1992). Criteria for determining nest-site fidelity, however, have varied among studies and often is subjective. For example, nest-site fidelity for cavity (e.g., woodpeckers, Picidae sp.) or nest-box (e.g.,

wood duck, *Aix sponsa*) species is readily determined due to the spatial distribution and nature of nest sites. For other bird species which may not use the exact nest sites as previous years, however, determining fidelity is more subjective. In this instance, past researchers have defined fidelity as mean Euclidean distances between nests (e.g., range 0-1,100 m) (Shields 1984; Berry & Eng 1985; Parmelee & Pietz 1987; Toepfer & Newell 1987; Williams & Rodwell 1992) or use of a pre-defined area or territory (e.g., range 1-61 ha) (Gauthier 1990; Ingold 1991). Problems associated with these methods include difficulty in determining a minimum distance or area which defines nest-site fidelity (Jenkins & Jackman 1993; Reed & Oring 1993). Another limitation of this approach is that the observed “fidelity” may be a result of limited nest sites. A method of determining nest-site fidelity among non-cavity nesting birds that is quantitative and considers available nesting habitat is described in this paper. The proposed statistical approach is illustrated using data from 12 radio-tagged eastern wild turkeys (*Meleagris gallopavo silvestris*). Previous studies (Hillestad & Speake 1970; Healy 1992; Vangilder & Kurzejeski 1995) have reported wild turkeys to exhibit nest-site fidelity.

MATERIALS AND METHODS

Data collection.—Twelve eastern wild turkey hens were captured in January 1994, translocated, and released into Grimes County, Texas, under the direction of Texas Parks and Wildlife Department biologists. Before release, all birds were fitted with a battery-powered radio transmitter (150-152 MHz, 115 g, Advanced Telemetry Systems, Isanti, Minnesota) and Texas Parks and Wildlife Department leg bands (Lopez et al. 1997; Lopez et al. 1998). Transmitters were attached using a 0.3-cm shock-cord harness (Williams et al. 1968, American Cord and Webbing Company, Woonsocket, Rhode Island), and birds were aged and sexed (Pelham & Dickson 1992).

During the nesting season (April-July; Vangilder & Kurzejeski 1995; Lopez et al. 1997), radio-tagged birds were monitored 3-4 times per week. All hens found at the same location for 8-10 successive days during this period were assumed to be incubating. Using homing techniques (White & Garrott 1990), nest sites were located, flagged, and sampled after incubation was complete, or the nest was abandoned (Lopez et al. 1997). Telemetry and nest-site locations were entered into a geographic information system (GIS) using ArcView (Environmental Systems Research Institute [ESRI], Version 3.2) and Microsoft Access. Color infrared photos of the study area also were entered into the GIS and used to delineate cover types (e.g., forest, pasture, water).

Data analysis.—Radio-tagged turkeys monitored for multiple years (>1) were used to determine nest-site fidelity. For a given individual, a nesting range (100% minimum convex polygon; Mohr & Stumpf 1966) was calculated with the animal movement extension in ArcView (Hooge & Eichenlaub 1999). The nesting range of a radio-tagged hen was determined from telemetry locations collected one month prior to nest incubation (Vangilder & Kurzejeski 1995; Lopez et al. 1997). Only birds with ≥ 20 locations were used in determining range estimate (Silvy 1975). The nesting range (hereafter called total nesting range) for the first-year nesting attempt was used as a baseline, with subsequent nest sites compared to the first year's range.

For each bird, a nesting-range vector polygon was converted to raster or grid cells using ArcView's Spatial Analyst (ESRI Version 1.1; Aronoff 1993). Pixel resolution (i.e., pixel or cell size) was resampled to equal 100 m by 100 m (1 ha). This resolution was determined by the level of precision used in calculating the nesting range. In this case, the grid-cell size (1 ha) was equal to the associated telemetry error polygons (White & Garrott 1990). Since raster models allow overlay functions to be easily implemented (Aronoff 1993), areas not considered suitable nesting habitat (e.g., urban development, water) could be excluded in the tabulated nest-

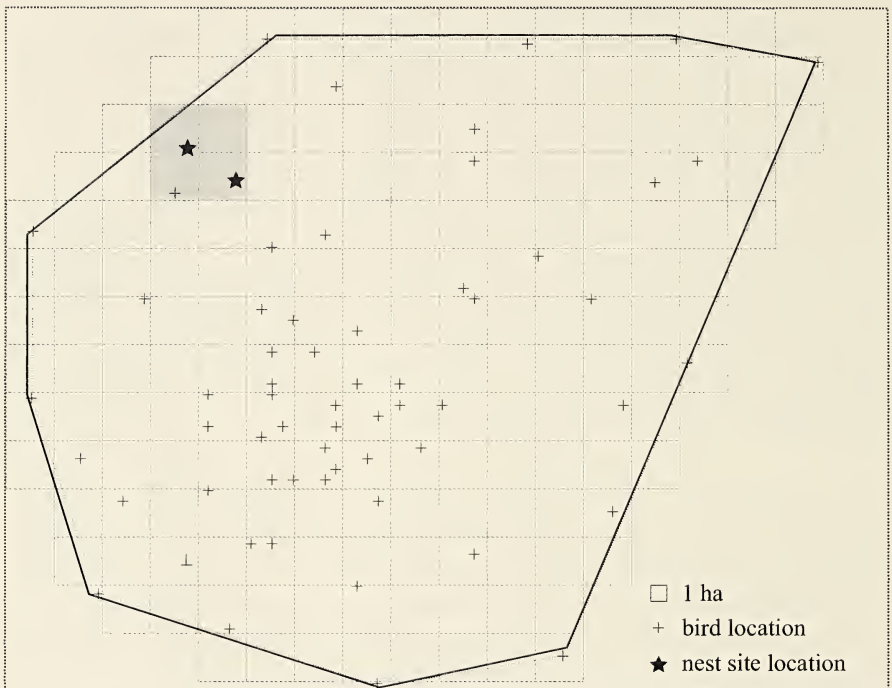


Figure 1. Quantitative technique used to determine nest-site fidelity for female wild turkeys. Individual annual range was (minimum convex polygon, line) determined using ArcView. The nesting-range vector polygon of an individual turkey was then converted to a raster grid, and individual cell probabilities (one cell/total cells) were calculated. Nest-site fidelity was assumed to exist if nest range (i.e., a square that encompasses all nest sites, shaded gray) was $< 1/20$ ($P < 0.05$) of nesting range (1 month prior to nest incubation, first year). In this example, the calculated probability was $P = 0.021$ (4/187 ha cells).

ing range. Individual cell probabilities (1 cell/total cells within range) were then calculated. The null hypothesis (i.e., nest-site selection was random between years) was tested at an alpha level of 0.05. Nest-site fidelity was assumed if all nest sites were within $1/20$ ($P = 0.05$) of the total nesting range. The nest-site-fidelity area ($1/20$ of annual range) was determined by forming a square that encompasses all nest sites (Figure 1). The nest-site fidelity area represents the probability of an individual hen nesting within

Table 1. Computation of nest-site fidelity for radio-tagged eastern wild turkeys in Grimes County, Texas, 1994-1995.

Bird number	Nesting range ^a	Nest-site fidelity area ^b	Nest distance ^c	<i>P</i>
1	228	56	815	0.158
2	187	4	159	0.021*
3	81	9	395	0.111

^a Individual nesting range (100% minimum convex polygon, ≥ 20 locations, one month before nest incubation).

^b Area (square) that includes all nest sites between years.

^c Euclidean distance between nests.

* Hens exhibiting nest-site fidelity.

this area between consecutive years. This same approach could be conducted using vector data instead if desired.

RESULTS AND DISCUSSION

The ability to quantify nest-site fidelity provides the opportunity to address reproductive success in context of spatially-explicit landscape characteristics. This approach is especially informative where intensive habitat-management practices (e.g., prescribed fire, selective thinning) are routinely applied. A common problem in avian research has been the lack of standardized methodology to quantify nest-site fidelity (Shields 1984; Berry & Eng 1985; Parmelee & Pietz 1987; Toepfer & Newell 1987; Williams & Rodwell 1992). The majority of these researchers defined fidelity as mean Euclidean distances between nests. This study was part of a larger research effort which focused on the ecology of transplanted eastern turkeys (Lopez et al. 1998), which were being reintroduced to areas formerly occupied by this species. Transplanted turkeys in the study suffered high mortality ($n = 9$, Lopez et al. 1998) and consequently study sample sizes were small. Despite the small sample ($n = 3$) of available turkey hens (birds that nested for two consecutive years within their first-year range), one of three

female turkeys exhibited nest-site fidelity using this method (Table 1).

The proposed statistical approach in determining nest-site fidelity is spatially explicit and makes no assumptions about the distribution of the underlying data (Conover 1980). Furthermore, the technique allows for varying amounts of suitable nesting habitat to be considered when determining nest-site fidelity. As such, this approach provides a standardized format for quantifying nest-site fidelity that is easy to use, spatially explicit, and repeatable across studies. One disadvantage of this technique is that it can only be used with radiotagged animals. Alterations of this method with non-telemetry data is encouraged in the future. Here a theoretical framework quantifying nest-site fidelity is presented, however, it is recommended further research in the use of this method be conducted.

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ZAPATA BLADDERPOD
(*LESQUERELLA THAMNOPHILA* ROLL. & SHAW):
ITS STATUS AND ASSOCIATION WITH OTHER PLANTS

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Abstract.—Zapata bladderpod (*Lesquerella thamnophila*) is an endangered plant found in eight populations in Starr and Zapata counties of southern Texas. The spatial associations between Zapata bladderpod and other plants at one location in Starr County, Texas, between 1997 and 2003 were investigated. Based on densities at sampling plots, the mean population of Zapata bladderpod at the 18.2 ha study site was 3,146 with a high of 8,351 in July 1997 and a low of 826 in March 2001. Zapata bladderpod demonstrated a clumped distribution and significant nonrandom association with associate ($P < 0.01$) and canopy plants ($P < 0.01$). Most Zapata bladderpods (70.3%) were classified as mature and vegetative. Of all Zapata bladderpods sampled, 18.3% were in fruit, 10.2% were characterized as young plants, and 1.2% were in flower. Considerations for future research are discussed.

Zapata bladderpod (*Lesquerella thamnophila* Roll. & Shaw) (Brassicaceae) is a federally endangered mustard found in Starr and Zapata counties in South Texas (U.S. Fish and Wildlife Service [USFWS] 1999). Zapata bladderpod is restricted to gravelly to sandy loam soils originated from Eocene sandstones and clays (Poole 1989). It may also be found in northern México due to the presence of similar habitats. Although one specimen has been reported from Tamaulipas, México, the site has not been revisited (USFWS 2004).

Zapata bladderpod is silvery-green perennial with sprawling stems (Poole 1989). Each Zapata bladderpod has a basal rosette of leaves from a single rootstalk. Leaves are narrowly elliptical to oblanceolate and acute and have entire to slightly toothed margins. The inflorescence is a loose raceme of yellow petals that appear more commonly after sufficient rainfall in the warmer seasons.

From 1997 to 2002, the site discussed herein contained the largest known population in Texas although a recently discovered

population in Starr County (T. Patterson, pers. comm.) 17.3 km from the current study site may be larger. Eleven populations were known historically and only eight are known today with the addition of another newly discovered population on 30 March 2004 (C. Best, pers. comm.).

Prior to this study no published data were available regarding Zapata bladderpod abundance, phenology, or spatial distribution with respect to conspecifics or other plants. The current study presents population estimates of Zapata bladderpod from one population in Starr County from 1997, 2001, 2002, and 2003, and the spatial association between Zapata bladderpod and other plants in 2003.

MATERIALS AND METHODS

The study area is in western Starr County, Texas, and is comprised of 18.2 ha of Chihuahuan Thorn Forest biotic community (Jahrsdoerfer & Leslie 1988) within the larger area that Blair (1950) referred to as the Tamaulipan Biotic Province. Common plants of the study area include blackbrush acacia (*Acacia rigidula*), cenizo (*Leucophyllum frutescens*), *Euphorbia prostrata*, oreja de perro (*Tiquilia canescans*), and skeleton-leaf goldeneye (*Viguiera stenoloba*). The landscape of the area is characterized by gentle slopes and eroding soils. The soils belong to the Catarina series of the Catarina-Copita association (Thompson et al. 1972). The soils are deep to moderately deep salty clays and some areas have gravelly to sandy loams (Poole 1989). An intermittent creek bisects the study area and is vegetated by denser brush than the surrounding area. Prior to 1990, several areas on the tract were cleared in preparation for residential development.

During an exhaustive search of the tract in July 1997, Zapata bladderpod were marked to determine where the largest concentrations occurred. Zapata bladderpod were not observed in the creek channel although a few were found along the overhang of the creek. Because of the lack of bladderpod, the creek channel was not

considered habitat for Zapata bladderpod and the study area was split in two parts. Zapata bladderpods farthest from the two sub-population centers were used to form the boundaries of the population. Boundaries of the population of bladderpod were determined by marking a straight line between plants on the periphery of the group. Distance between these plants was usually less than 13.4 m. After determining the extent of the population, the perimeters of both areas were mapped using a Trimble MC-V global positioning unit and data were corrected for selective availability using a base station at Santa Ana National Wildlife Refuge, Alamo, Texas.

A systematic random sampling method was used to distribute 30 sampling plots across the Zapata bladderpod population area. Sampling plots were located using a Trimble MC-V. Each sampling plot was permanently marked for population monitoring by the USFWS using a rebar stake. The rebar stakes served as the center for each 3-m radius-sampling plot.

Zapata bladderpod surveys were conducted on 31 July 1997, 15 March 2001, 15 June 2001, 10 September 2002, and 22 September 2003. Zapata bladderpods observed on plots were classified based on their stage of developmental condition: (1) young plant, i.e., no dead leaves attached and all leaves formed angles with the surrounding soil at more than 45 degrees, (2) mature vegetative, i.e., presence of only a basal rosette of leaves and possibly bare pedicels, (3) mature with flower, and (4) mature with fruit.

The developmental condition for each flowering pedicel on each bladderpod was recorded. When different developmental conditions were present on the same bladderpod, e.g. pedicels with flowers and fruit, the presence of fruit was considered the priority. A deteriorated flower with a developing or developed ovary was considered to be in fruit, as well as a pedicel with any part of the seed capsule remaining attached to the pedicel. The number of pedicels was recorded for each plant. Based on field observations of root systems of bladderpod found on eroding soils, each basal

rosette of leaves was assumed to come from a single rootstalk; therefore, each rosette was classified as an individual plant.

The spatial distribution of plants in relation to Zapata bladderpod was recorded from the sampling plots in September 2003. Any plant taller than 0.5 m and directly above the basal rosette of a bladderpod was recorded as a canopy species. Any plant having foliage within 10 cm horizontally of a bladderpod and not recorded as a canopy species was recorded as an associate species.

For comparison of frequencies of use and availability of plant species as canopy and associate to Zapata bladderpod, the canopy and associate plants present in the plant community were recorded at sampling locations within the tract. During the general vegetation survey in September 2003, a systematic random sampling method was used to distribute 30 sampling locations over the entire 18.2 ha tract using Pfinder 5.0 software. These points were then located for sampling using a Garmin 12. Three nested circular plots at each sampling location were established one meter from the sampling stake at bearings of 90°, 210°, and 330°. Plot radius was based on the average longest-leaf of local Zapata bladderpods (11 cm) plus the 10 cm horizontal distance as used in the Zapata bladderpod survey. Thus, any plants taller than 0.5 m were recorded as a canopy species and any plant not recorded as a canopy species and having foliage within 21 cm horizontally from the sampling stake was recorded as an associate species.

The null hypothesis that there were no significant differences among frequencies of use and availability of each plant species as canopy or associate to Zapata bladderpod was tested using chi-square tests ($\alpha = 0.01$). The coefficient of dispersion (Brower et al., 1998) was used to examine departure from random spatial distribution of Zapata bladderpod ($\alpha = 0.01$). Plant taxonomy follows Correll & Johnston (1970) and Richardson (1995).

The previous one month, two months, six months, and 12 months of total precipitation based on data from a weather station 1.47 km away at Falcon Dam, Texas (National Oceanographic and Atmospheric Administration [NOAA] 2003), were assessed for correlation with Zapata bladderpod abundance.

RESULTS

Zapata bladderpod population estimates ranged from 826 to 8,351 individuals based on extrapolation from the mean number of Zapata bladderpod per plot and the size of the bladderpod population area (Table 1). The spatial distribution of Zapata bladderpod was significantly clumped across all population surveys (July 1997: $\chi^2 = 140.68$, $df = 29$, $P < 0.01$; March 2001: $\chi^2 = 58.24$, $df = 29$, $P < 0.01$; June 2001: $\chi^2 = 71.99$, $df = 29$, $P < 0.01$; September 2002: $\chi^2 = 49.04$, $df = 29$, $P < 0.01$; September 2003: $\chi^2 = 48.98$, $df = 29$, $P < 0.01$).

Most Zapata bladderpod (70.3%) were classified as mature and vegetative ($n = 44$). Only 1.2% of the bladderpod were in flower while 10.2% of the bladderpod were characterized as young plants, and 18.3% had fruit. Zapata bladderpods were observed in flower during June 1997, June 2001, July 2002, September 2002, and September 2003. Most of the bladderpod that had flowering pedicels in 1997 had three (12.9%), two (10.4%), or one (10.6%) ($n = 116$) and the maximum number of flowering pedicels on any bladderpod was fourteen. Damage by insects on the seeds of Zapata bladderpod was evident due to the presence of small holes in the capsules of many plants and the lack of seeds.

During the Zapata bladderpod survey 22 canopy species were recorded. Twenty-six plant species were recorded as canopy species during the general vegetation survey. Although about 17% of the vegetation samples had no canopy species, all Zapata bladderpod had at least one canopy species. Zapata bladderpod demonstrated non-random spatial association with canopy species ($\chi^2 = 489.21$, $df = 34$, $P < 0.01$) (Table 2).

Table 1. Survey dates, means of samples with standard error of the mean (SE), and the population estimates based on extrapolations of the means to the Zapata bladderpod population area.

Survey date	Sample mean	Population estimate
22 September 2003	3.00 (1.18)	1,902
10 September 2002	2.43 (1.06)	1,543
15 June 2001	4.90 (1.80)	3,108
15 March 2001	1.30 (0.84)	826
31 July 1997	13.17 (4.08)	8,351

Zapata bladderpod had a canopy more often than expected. The canopy species, Texas paloverde (*Cercidium texanum*) and buffleg-rass (*Cenchrus ciliaris*), accounted for the largest departures from random for the spatial distribution of bladderpods. Most bladderpods (38%) were found on one plot where both species provided canopy cover. With the removal of data at this plot and re-analysis, Zapata bladderpod still had a canopy significantly more often than did general vegetation plots ($\chi^2 = 112.19$, $df = 34$, $P < 0.01$). Many of the bladderpods in July 1997 and June 2001 (29% and 36%, respectively) were found on the same plot which had blackbrush, wolfberry (*Lycium berlandieri*), and coyotillo (*Karwinskia humboldtiana*) as canopy species.

During the Zapata bladderpod survey 37 associate species were recorded. Thirty-one plant species were recorded as associate species during the general vegetation survey. Zapata bladderpod demonstrated nonrandom spatial association with associate species ($\chi^2 = 2,267.53$, $df = 44$, $P < 0.01$). Zapata bladderpod and sideoats grama (*Bouteloua curtipendula*) accounted for the largest departures from random for associates.

Table 2. Frequencies of each Zapata bladderpod canopy or associate species rounded to the nearest integer. Data is presented for species that comprised at least 2% of the total observed or expected values of canopy or associate species.

Species	Canopy*		Associate**	
	Obs	Exp	Obs	Exp
Blackbrush (<i>Acacia rigidula</i>)	34	38	25	11
Blackfoot daisy (<i>Melampodium cinereum</i>)	–	–	13	5
Brush noseburn (<i>Tragia glanduligera</i>)	–	–	7	3
Bufflegrass (<i>Cenchrus ciliaris</i>)	10	1	4	15
Calderona (<i>Krameria ramosissima</i>)	–	–	1	5
Cenizo (<i>Leucophyllum frutescens</i>)	24	20	1	1
Coyotillo (<i>Karwinskia humboltiana</i>)	10	4	1	3
Dutchman’s breeches (<i>Thamnosma texana</i>)	–	–	28	11
<i>Euphorbia prostrata</i>	–	–	22	47
Leatherstem (<i>Jatropha dioica</i>)	6	1	–	–
None	–	24	1	24
Oreja del perro (<i>Tiquilia canescens</i>)	–	–	10	29
Parralena (<i>Dyssodia pentachaeta</i>)	–	–	10	9
Plains bristlegrass (<i>Setaria leucopila</i>)	2	1	3	6
Plains lovegrass (<i>Eragrostis intermedia</i>)	9	1	2	1
Red grama (<i>Bouteloua trifida</i>)	1	1	10	8
Ruellia (<i>Ruellia runyonii</i>)	–	–	3	5
Sideoats grama (<i>Bouteloua curtipendula</i>)	–	–	–	29
Skeleton-leaf goldeneye (<i>Viguiera stenoloba</i>)	–	–	2	5
Texas kidneywood (<i>Eysenhardtia texana</i>)	–	9	–	–
Texas paloverde (<i>Cercidium texanum</i>)	25	2	–	–
Tulipan del monte (<i>Hibiscus cardiophyllus</i>)	5	1	7	3
Wild oregano (<i>Lippia graveolens</i>)	–	9	–	3
Zapata bladderpod (<i>Lesquerella thamnophila</i>)	–	–	46	1

* $\chi^2 = 489.21, df = 34, P < 0.01$
** $\chi^2 = 2,267.53, df = 44, P < 0.01$

Strong relationships were found between population estimates and total precipitation from 12 months ($n = 5$, $r = 0.88$) and 6 months ($n = 5$, $r = 0.86$) prior to Zapata bladderpod surveys. Only a moderate relationship ($n = 5$, $r = 0.60$) was observed between population estimates and total precipitation from one month prior to surveys. A weak relationship ($n = 5$, $r = 0.21$) was observed between population estimates and precipitation totals from two months prior to bladderpod surveys.

DISCUSSION

Zapata bladderpods demonstrated a clumped spatial distribution during each survey. Roll et al. (1997) noted that reproductive success was higher among desert mustards (*Lesquerella fendleri*) that were within 1 m of one another and speculated that this was due to higher pollinator visitation rates among clumped individuals. A similar study could add significantly to knowledge of the biology of Zapata bladderpod.

Many Zapata bladderpods were found in areas that had been cleared during the previous owner's attempt to develop the property. In some places, bladderpod were growing next to piles of displaced soil. Zapata bladderpod may respond positively to some forms of surface disturbance. In June 2000 a small area of the property also containing Zapata bladderpod was cleared of tall brush for electrical utilities maintenance and the early successional community that developed seemed to favor rapid growth, flowering, and fruiting of Zapata bladderpod (C. Best, pers. comm.).

Although Zapata bladderpod demonstrated non-random use of canopy and associate species, there was not a strong tendency for Zapata bladderpod to use any one species except conspecifics as associate species. The use of conspecifics as associates by Zapata bladderpod is not likely a result of selection but rather a result of short-range seed dispersal.

Bufflegrass appeared to dominate a considerable portion of an adjacent privately-owned area where Zapata bladderpods were also present. Although bufflegrass was not a common species on the site, it was present along a large section of one of the fences and a few other areas within the study area in areas that apparently had been disturbed during road preparation. As bufflegrass and other non-native and invasive grasses pose a threat to the native plant community (Akhtar et al. 1978; Hussain et al. 1982), the dominance of these grasses and their effects on Zapata bladderpod should be monitored at the site.

February and March 2003 surveys at a recently discovered population contained 1,706 individuals (C. Best, pers. comm.). Site visits to five other populations demonstrated that many bladderpod were present and either in fruit or flower in early 2001, 2002, 2003, and that one population in an urban development in Zapata County may have been extirpated (D. Price, pers. comm.). When populations appear extirpated sampling should continue for several years as the desert mustard (*Lesquerella fendleri*) has seeds that remain viable in the soil for at least three years and dormant seeds that are genetically different from those that readily germinate (Evans & Cabin 1995).

Blackbrush is the dominant vegetation at the site. Blackbrush can act as a facilitator for plant recruitment possibly due to higher nitrogen and lower sulfur levels (Jurena & Van Auken 1998), as a focus for wind-deposited seeds (Howe & Smallwood, 1982), or protection from herbivores (Nabhan 1986). After approximately 8.3 cm of rain fell in the area in June 1999 (NOAA 2003), Zapata bladderpod not under brush canopies had more of the top portion of their roots exposed than bladderpod under brush canopies (USFWS 2004) suggesting that the presence of a canopy may be beneficial to bladderpod survivorship. Yet, many of the bladderpod observed in open canopy areas in this study had numerous flowering pedicels and were of considerable size. The effects of canopy as well as

associate species on Zapata bladderpod should be further investigated.

Zapata bladderpod seemed to be abundant in warmer seasons following several months of average rainfall rather than following a strictly seasonal phenology (see also Poole 1989, USFWS 2004). Carr (1995) documented only 26 individuals of Zapata bladderpod at the same site in June 1995. If total rainfall from the previous 12 months is an indicator of the abundance of Zapata bladderpod, then the low number of Zapata bladderpod observed by Carr would not be surprising as February 1993 to March 1994 had the lowest total 12 months of precipitation (33.5 cm) since February 1977 to March 1978 (32.7 cm) (NOAA 2003). A more thorough approach would examine monthly rainfall totals and bladderpod densities over several years to elicit more insightful relationships.

Having been established since at least 1993, the Zapata bladderpod population at the current site appears to be a self-sustaining population. Population data demonstrating self-sustainability are needed from 12 distinct and protected populations before Zapata bladderpod can be considered for reclassifying as a federally threatened species (USFWS 2004). Management of Zapata bladderpod should include continued research and monitoring of known populations and the purchasing and surveying of additional bladderpod habitats. Future research should include repeated surveys to examine temporal population variability, individual plant survivorship, fecundity, microhabitat characteristics, and provide data for the recovery of the Zapata bladderpod among all extant population sites in South Texas and northern México.

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EIGHT-YEAR EFFECTS OF PLASTIC TREE SHELTERS ON PLANTED BOTTOMLAND HARDWOOD SPECIES IN NORTHEAST ARKANSAS

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Abstract.—This study was implemented in northeastern Arkansas to compare the performance of planted bottomland tree species with and without tree shelters. Thirty-centimeter translucent polyethylene tree shelters were installed around approximately one-half of the seedlings. Survival and growth of Nuttall oak (*Quercus nuttallii* Palmer), willow oak (*Q. phellos* L.), bitter pecan (*Carya x lecontei*) and baldcypress (*Taxodium distichum* (L.) L.C. Rich) were evaluated during the eight years following planting. Hardwood species were planted on reclaimed agricultural land along recently disturbed borrow pits. Survival of Nuttall oak, willow oak and bitter pecan seedlings with tree shelters were significantly ($P < 0.05$) higher than seedlings planted without shelters for the eight years of the study. Overall, tree shelters increased survival from 43 to 73%. No significant differences were found for mean tree height, stem diameter or diameter at breast height (dbh) during the eight years of the study. The higher percentage of resprouted seedlings protected by tree shelters, 74 to 76%, indicates that the tree shelters may help protect the young emerging shoots from desiccation and herbivory. Data in this study suggest that the seedlings protected by the shorter tree shelters are comparable to results found in previous studies using taller tree shelters.

Prior to the arrival of European settlers, the Lower Mississippi Valley (LMV) was extensively covered by dense bottomland hardwood forests (Hamel & Buckner 1998). By the late 1930s only about one-half of the original area of forest remained (Allen & Kennedy 1989) with estimates of about two million hectares of bottomland hardwood forests remaining of the original 10 million hectares (MacDonald et al. 1979). Careful planning of reforestation efforts is an important step in restoring this ecosystem.

Tree shelters have been reported to (1) enhance early growth and survival of tree seedlings (Potter 1988; Smith 1993; Walters 1993), (2) protect seedlings from animal (Conner et al. 2000, Sweeney et al. 2002), mechanical and/or herbicide damage (Sweeney et al. 2002) and (3) reduce competitive effects from nearby vegetation (Hunt 1996; Sweeney et al. 2002). In studies involving Nuttall oak (*Quercus nuttallii* Palmer), plastic tube shelters stimulated both greater seedling

height and diameter growth (Schweitzer et al. 1999; Taylor & Golden 2002). In contrast, Twedt & Wilson (2002) found that tree-shelter-protected seedlings of sycamore (*Platanus occidentalis* L.) and cottonwood (*Populus deltoides* Bart. Ex Marsh.), planted throughout the LMV, had decreased survival with no significant increase in tree height after one growing season. Red oak (*Quercus rubra*) planted in southern Ontario showed reduced dieback and increased height growth of seedlings with tree shelters (Strobi & Wagner 1996). Stringer (1996) found survival of *Paulownia tomentosa* (Thunberg) Steudel (royal paulownia) increased from 40 to 80% with the use of tree shelters. Red oak seedlings planted in Maryland (Sweeney et al. 2002), Missouri (Ponder 2003), Pennsylvania (Walters 1993) and West Virginia (Smith 1993) also showed increased survival and height growth with seedling tree shelters.

In the previously mentioned studies, tree shelters, approximately 1 to 1.2 meters tall, were used to protect the seedlings. The results of these studies generally support the idea that greater survival can be achieved using plastic tree shelters. Tree shelters of minimal height (30 cm) were used in this study to evaluate their effect on survival and growth of trees 1, 2, and 8 years after planting on reclaimed agricultural land. Tree shelters of shorter height can be considerably less expensive and may provide some of the same benefits afforded by the taller shelters. The objective of this study was to determine the success of reforestation efforts of this project in the St. Francis Basin, Poinsett County, Arkansas. This study examines the effects of tree shelters on hardwood seedling survival and growth in a reforestation effort in northeastern Arkansas.

METHODS AND MATERIALS

Site descriptions.—The Marked Tree Demonstration Site is located in Poinsett County, Arkansas, west of Marked Tree and north of U.S. Highway 63. The study area is a 124-acre (50 ha) tract in the St. Francis Basin Floodway. This area typically floods in the spring and is dominated by grass and weeds, with few trees.

Published county soil survey maps were consulted to determine the soil series in the study area. In the first year (1996), soils in the study area were identified as being of the Sharkey-Steele series which is a

complex made up of mounds of Steele soils between Sharkey soils. The study site is primarily composed of Steele soils. The Steele soils have a 25 to 50 cm sandy upper layer, underlain by Sharkey clay. Because of recent disturbances by dredging operations one year prior to planting, some of the upper surface layer has been removed in restricted areas during the construction of the borrow pits and levee work. Soils on the site were comparable to similar soils in the LMV of the same series and were similar to those published (Broadfoot 1976; Francis 1986) for Mississippi alluvial soils associated with bottomland forests.

Prior to planting, the study area was mowed as part of the site preparation. In April 1996, 1-0 bareroot seedlings were planted at the study site at about a 10 by 10 foot (3 m by 3 m). Bare root seedlings of willow oak, Nuttall oak, bitter pecan and baldcypress were planted with a minimum height of 30 to 45 cm. Species were not randomly planted, instead to the extent possible, species were planted at positions on the landscape according to their moisture requirements/flooding tolerance.

In late May 1996, sixteen 0.02 hectare (0.05 ac) permanent regeneration plots were established to record planting success on the site. An additional eighteen plots were established about 4 weeks later. Sampling was conducted to quantify the survival and growth of tree seedlings at the end of the 1996, 1997 and 2003 growing seasons. The area planted ranged from approximately 10 to 50 m in width.

During the dormant period between the 1996 and 1997 growing seasons, over bank flooding, flowing within the St. Francis Floodway Levee System, eroded soil and washed away seedlings. The soil in this area has a sandy upper layer, from which the flood waters easily uprooted the shallow-rooted seedlings. Seedling loss between the 1996 and 1997 growing season was estimated at approximately 3% using data collected on the plots at the beginning of the 1997 growing season. In these locations, complete loss of vegetation exposed bare mineral soil. Data from these locations were not included in the analyses. The remainder of the site was essentially continuously flooded from November 1996 through March 1997, to an average depth of 25 cm.

Tree shelters & herbaceous competition.—After seedlings were planted, 30 cm translucent polyethylene tree shelter tubes (Tree Pro Tree Shelters, Lafayette, IN) were installed around approximately one-half of the randomly chosen seedlings. The tree shelters were staked with bamboo and secured with nylon ties. In May 1996, glycolphosphate herbicide was applied within a 45-cm radius of the seedlings, with and without tree shelters. No observable damage from overspray by the herbicide treatment was seen in the planted seedlings. Late during the 1996 and 1997 growing seasons, two 1-square-meter sub-plots were taken from each of the 16 permanent plots to assess competition surrounding the seedlings. Vegetation samples were taken to the lab, dried at 60°C, sorted and weighed. Data were then expressed as biomass (kg dry weight) per hectare.

Seedling measurement.—On each plot, seedlings were monitored at the end of the 1996 growing season, the beginning and the end of the 1997 growing season, as well as at the end of the 2003 growing season. A complete census of the seedlings on each plot was taken. Stem height, basal diameter at 1 in (2.5 cm) above the ground, and survival of each species were recorded during each sampling period in each plot. Volunteer and residual seedlings were also tallied. Volunteer seedlings were defined as those individuals that germinated after the planting date. Residual seedlings are those that were either on the site at the time of planting or re-sprouted from rootstock after the area was mowed. Once trees were 4.5 ft (135 cm) tall or taller, measurement of diameter at breast height (dbh) was initiated, and basal diameter measurements were discontinued.

Statistical Analysis.—Analysis of variance (*ANOVA*) was used to test differences between seedlings with and without shelters using PC-SAS (SAS Institute, Cary, NC, USA). Multiple-comparison of means were conducted using Tukey-Kramer multiple range test when the *ANOVA* indicated statistical significance ($p \leq 0.05$). Differences between means were considered to be significant when $p \leq 0.05$. Prior to analysis, the data were tested for normality, and if needed, transformed to normalize their distribution. Percentage data were transformed using the arcsin transformation.

RESULTS

Overall seedling survival performance.—Competing vegetation on most plots was taller than planted seedlings. However, chemical control of vegetation had effectively reduced the competition immediately around individual seedlings. At the end of the second growing season, September 1997, dry weight of herbaceous vegetation biomass was only slightly less, 1,174 kg/ha (1,047 pounds/ac), than at the end of the previous growing season, September 1996, 1,380 kg/ha (1,231 pounds/ ac).

Target planting density called for 436 trees per acre (TPA) or 1,077 trees per hectare. Measured planting density was 430 ± 13 (mean $\pm$ s.e.) TPA, excluding volunteer and residual trees which measured 47 ± 18 TPA. The planting density ranged from 260 to 517 TPA (642 to 1,277 trees per ha). Initial mean heights of planted seedlings were not significantly different for each species for those seedlings planted with or without tree shelters. Initial average height was greatest for baldcypress at 0.7 m, Nuttall oak at 0.51 m, willow oak at 0.40 m, and lowest for bitter pecan at 0.36 m. No significant differences were found in seedling basal diameter for those seedlings with or without tree shelters.

First year survival, 1996, for the planted seedlings was low at about 58%. On the measured plots overall survival was 249 ± 30 TPA, or 57.9%. Survival rate varied from 54 to 517 TPA (133 to 1277 trees per ha), or 20 to 100%. Nuttall oak was the most frequently planted species on the study site (Table 1). Bitter pecan appeared to lose height growth when compared to the height of the initially planted seedlings, 0.36 m at the end of the 1996 season versus the 0.40 m initial height.

In 1997, survival for planted seedlings was low at about 56%, or 246 TPA (610 trees per ha) (Table 1). The survival rate was as high as 100% on two of the 32 plots, to 5% on one of the plots. In 2003, overall survival was comparable to the two earlier sampling years at 56%. At the end of the second growing season, Nuttall oak density was 114 TPA (calculated as 34% of 105 TPA + 74% of 106 TPA; Table 1) and was significantly lower than in 1996, indicating mortality in this species. In contrast, willow oak, bitter pecan and bald-

Table 1. Mean survival for Nuttall oak, willow oak, bitter pecan and baldcypress planted on the Marked Tree, Arkansas land reclamation site, with and without tree shelters for 1996 (year 1), 1997 (year 2) and 2003 (year 8).

Species	Tree shelter treatment	Seedlings planted	Year		
			1996	1997	2003
		TPA ²	(%)	(%)	(%)
Nuttall oak	without	105	63 ± 6.6a ¹	34 ± 9.9a	36 ± 8.1a
	with	106	88 ± 10.7 b	74 ± 8.1b	72 ± 5.7b
Willow oak	without	44	27 ± 5.7a	19 ± 6.7a	21 ± 3.8a
	with	51	57 ± 8.9b	49 ± 11.1 b	49 ± 4.8b
Bitter pecan	without	20	7 ± 3.2a	37 ± 12.2a	37 ± 9.7a
	with	21	50 ± 11.1 b	79 ± 5.7b	75 ± 3.8b
Baldcypress	without	41	75 ± 20.9a	77 ± 10.2a	76 ± 7.1a
	with	42	87 ± 16.4a	84 ± 18.6a	80 ± 15.2a

¹ Mean ± standard error of the mean for tree shelters treatments for a species in a column followed by a different letter are statistically different at the $P \leq 0.05$ level by Tukey's Studentized Range Text.

² Trees per acre.

cypress did not show a significant decline in seedling density. Mean seedling height was greatest for baldcypress followed by Nuttall oak, willow oak and bitter pecan (Table 2). Seedling diameter, measured at the root collar, was greatest for baldcypress and willow oak, followed by Nuttall oak and bitter pecan.

After 8 growing seasons, average seedling height for Nuttall oak, willow oak, bitter pecan and baldcypress were 2.9 m, 2.7 m, 2.2 m and 2.0 m, respectively (Table 2). Average diameter at breast height (dbh) for Nuttall oak, willow oak, bitter pecan and baldcypress were similarly ranked (Table 2).

Seedling Shelter Performance.—Polyethylene shelter tubes were placed on 51% of the planted seedlings. The tree shelters increased overall survival (72%), compared with 43% for seedlings without tree shelters at the end of the first year. Tree shelters significantly improved survival of all species, except baldcypress, and the effects remained through year 8 (Table 1). Seedlings of Nuttall oak, willow oak and bitter pecan planted with tree shelters, had mean survival rates double that of those without shelters. Tree shelters did not significantly affect total height in any of the species planted for the years studied (Table 2). Basal diameter of planted seedling was signi-

Table 2. Mean height and diameter for Nuttall oak, willow oak, bitter pecan and baldcypress planted on reclaimed land at the Marked Tree, AR site for years 1996 (year 1), 1997 (year 2) and 2003 (year 8).

Species	Tree Shelter	Year		
	Treatment	1996	1997	2003
Height				
Nuttall oak	without	0.60± 0.03a ¹	0.66± 0.03a	2.68± 0.15a
	with	0.58± 0.03a	0.64± 0.03a	3.15± 0.15a
Willow oak	without	0.47± 0.03a	0.58± 0.02a	2.65± 0.15a
	with	0.44± 0.03a	0.53± 0.03a	2.81± 0.30a
Bitter pecan	without	0.41± 0.09a	0.49± 0.02a	2.33± 0.25a
	with	0.35± 0.03a	0.36± 0.04b	1.96± 0.16a
Baldcypress	without	0.71± 0.03a	0.78± 0.03a	1.97± 0.11a
	with	0.68± 0.03a	0.72± 0.02a	2.08± 0.16a
Basal Diameter ² (cm)				
DBH (cm)				
Nuttall oak	without	0.82± 0.03a	0.96± 0.05a	2.74± 0.26a
	with	0.87± 0.04a	0.99± 0.07a	3.52± 0.27a
Willow oak	without	0.63± 0.08a	0.75± 0.03a	2.41± 0.27a
	with	0.64± 0.04a	0.77± 0.06a	2.32± 0.30a
Bitter pecan	without	0.76± 0.06a	0.80± 0.03a	2.10± 0.40a
	with	0.55± 0.06b	0.63± 0.05b	1.50± 0.14a
Baldcypress	without	0.86± 0.04a	1.26± 0.11a	1.62± 0.20a
	with	1.25± 0.12b	1.67± 0.10b	2.04± 0.43a

1 Mean ± standard error of the mean for tree shelter treatments for a species in a column followed by a different letter are statistically different at the $P \leq 0.05$ level by Tukey's Studentized Range Test (HSD).

2 Basal diameter measured at 2.5 cm above the ground.

ificantly greater in baldcypress seedlings planted with tree shelters for years 1 and 2 (Table 2). In contrast, basal diameter of bitter pecan, with tree shelters, was significantly smaller than those planted without tree shelters for years 1 and 2. Tree shelters for all species did not significantly affect height or dbh, measured at the end of year 8.

Re-sprouted seedlings.—Some of the seedlings at the end of the 1996 growing season were recorded as being dead, but by the following spring they re-sprouted from the remaining root. Nearly 48% of the bitter pecan seedlings planted, that were still alive at the time of sampling, were a result of re-sprouting (Table 3). This compares to 24% and 11%, for willow oak and Nuttall oak, respectively. Sheltered versus non-sheltered seedlings responded differently in terms of their tendency to re-sprout. In bitter pecan, willow oak and

Table 3. Re-sprouts and height of planted seedlings at the Marked Tree, Arkansas Land Reclamation Site¹.

Species	Seedlings Re-sprouted	Percentage of Re-sprouted Seedlings in Tree Shelters	Height of Re-sprouted Seedlings ²
	%	%	m
Nuttall oak	11.4	74.0	0.27± 0.01
Willow oak	24.0	74.2	0.22± 0.01
Bitter pecan	47.7	76.4	0.24± 0.01
Baldcypress	0	0	—

¹ Measured at the beginning of the second growing season (May 1997).

² Values are mean height ± standard error of the mean of seedlings which have re-sprouted from the original seedling stock.

Nuttall oak, 76%, 74% and 76%, respectively, of the seedlings which re-sprouted were enclosed by tree shelters. No significant differences in seedling heights were found between the species that re-sprouted (Table 3).

Volunteer and Residual Seedlings.—Volunteer and residual seedlings accounted for 10% (47 TPA) of the seedling density measured in year 1 (Table 4). Green ash (*Fraxinus pennsylvanica* Marsh.), eastern cottonwood and Nuttall oak comprised nearly equal amounts of the species measured, approximately 15 TPA each. The average height of these seedlings was generally greater than the planted seedlings. In year 8, volunteer and residual species accounted for 52% (259 TPA) of the tree species measured in 2003 (Table 4). Green ash and slippery elm (*Ulmus rubra* Muhl.) were the predominant species tallied in 2003, with the remaining species in approximately equal proportions (Table 4).

DISCUSSION

The primary objective of this eight-year study was to evaluate the influence that tree shelters have on reforestation efforts on this alluvial site. Most mortality occurs during the first year after planting. Nearly half of the measurement plots experienced greater than 50% mortality and four plots had a mortality rate of 80%. Overall, tree shelters had a positive impact on seedling survival, increasing survival from 43% to 72%. The largest impact on first-year survival was found with bitter pecan where survival was increased from 7% to 50% during the first

Table 4. Seedling density (TPA) and height data for Marked Tree, Arkansas Land Reclamation Site for volunteer and residual species for 1996 (year1) and 2003 (year 8).

	1996		2003	
	Density ¹ TPA ³	Height ² m	Density ¹ TPA	Height ² m
Green ash	15.0± 2.6	0.60± 0.04 (n=23)	86.0± 35.5	2.57± 0.10 (n=84)
Cottonwood	15.0± 2.6	0.65± 0.05 (n=23)	24.1± 21.7	4.63± 0.34 (n=27)
Nuttall oak	14.5± 2.5	0.66± 0.02 (n=21)	16.0± 4.5	2.92± 0.11 (n=34)
Black willow	2.4± 0.4	0.97± 0.09 (n=4)	27.2± 14.8	2.40± 0.04 (n=5)
Slippery elm	—	—	4.5± 36.4	2.59± 0.12 (n=32)
Boxelder	—	—	26.51± 5.6	2.05± 0.10 (n=16)
Sweetgum	—	—	33.7± 8.6	2.28± 0.32 (n=6)
TOTAL	47.5± 8.1	—	259.0± 14.8	—

¹ Values are means ± standard error of the mean of 34 & 21 sample plots, for year 1 and 8 respectively.
² Values are means ± standard error of the mean (n sample size).
³ Trees per acre.

year. But no significant impact was seen with baldcypress.

Second-year growing season data was influenced by seasonal flooding. Seedling survival at the end of the 1997 growing season was 57% (240 TPA), below the target density of 60% (260 TPA). However, volunteer seedlings from adjacent seed sources increased the tree species density to 276 TPA. Approximately 3% of the planted seedlings, or 1% of the 1996 surviving seedlings, were washed away. Nearly 60% of the tree shelters installed on trees in one sampling plot were washed away by floodwater and were later replaced. Seedlings planted in tree shelters, on floodplains, may be the first to be washed away. The apparent decline in seedling height for bitter pecan protected by tree shelters was because a significant proportion of the bitter pecan seedlings, 48%, were re-sprouts of which many (76%) were in tree shelters. In the first year, the stem died and a new smaller shoot was produced from the root collar. The presence of re-sprouted seedlings observed at the beginning to the second year (1997) indicates that the tree shelters may help protect the

young emerging shoots from detrimental conditions such as desiccation and herbivory.

Reports in the literature predict that the lighter seeded species (e.g., green ash, eastern cottonwood and sweetgum (*Liquidambar styraciflua* L.) would colonize a site from surrounding seed sources (Ashby et al. 1980; Gilbert et al. 1981; Johnson 1983). The data collected in this study supports these findings. At the end of year 8, these lighter-seeded species accounted for about 50% of the stems measured on the site. These volunteer species are faster growing and thus the greater height of these species was expected. Recruitment by light-seeded species on this project site was enough to insure a more diverse forest stand.

Overall, shelters significantly increased survival throughout the 8 years of this study for Nuttall oak, willow oak and bitter pecan. Increase survival may have been due to potentially better soil water potentials or other physiological advantages facilitated by the shelters. No significant increase in height growth, or effect on diameter growth was seen as in previous studies for those seedlings protected by tree shelters (Potter 1988; Schweitzer et al. 1999; Conner et al. 2000; Taylor & Golden 2002). Mean tree height for Nuttall oak, with and without tree shelters, was consistent with findings in the literature (Stanturf et al. 1998). The lack of a significant effect on growth, for those seedlings protected by tree shelters, is most likely due to use of shorter tree shelters 30 cm (12 inches) than previous studies utilized. Previous studies have shown that taller 1 to 1.5 m (4 to 5 ft) tree shelters stimulate height growth, while decreasing stem diameter. This growth pattern is thought to be the result of the reallocation of resources to allow the seedling to emerge above the plastic shelters (Lantagne et al. 1990). However, in this study we have demonstrated the value of the shorter tree shelters for increased survival, and for the protection of seedlings that re-sprout from roots of planted seedlings from the previous growing season.

CONCLUSIONS

The estimated cost of the shelters is approximately \$195/acre (\$0.45 per seedling) plus labor, for a planting density of 430 TPA.

The expense of tree shelter may however be prohibitive except in cases where herbivory is intense or where high survival is a requirement. Tree shelters, in addition to protecting plants from animals and competition from vegetation, aid in the establishment and early growth of planted hardwood seedlings. Studies previously cited, most in non-peer reviewed journals, have found accelerated height growth related to seedling protected by taller tree shelters. Ponder (2003) questions the long-term ability of these trees to maintain the height advantage once the seedlings emerge from the tree shelters. The shorter tree shelters used in this study did aid in the establishment and increased survival of planted hardwoods but did not increase seedling height. If the goal is to establish hardwood seedlings, with less emphasis on height growth, the data in this study suggest that seedlings protected by shorter (30 cm) tree shelters should perform very well in the establishment of hardwood forests.

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A COMPLETE CHARACTERIZATION OF ABELIAN GROUPS VIA SUBTRACTION

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Abstract.—Subtraction has always been considered secondary to the fundamental and primary operation of addition, in some measure because addition is associative while subtraction is not. This note shows how to obtain an abelian group with an addition like operation (Joyner 2002:70-72) beginning with a subtraction binary operation.

Definition 1: An ordered pair $(S, -)$, with S a non-empty set and $-$ being a binary operation on S , is called a subtractive groupoid if (1.) $(a - b) - (c - d) = (d - b) - (c - a)$ for all a, b, c, d in S and (2.) there exists an element 0 in S such that $a - 0 = a$ for all a in S and $a - b = 0$ if and only if $a = b$.

Theorem 1: 0 is unique.

Proof: Suppose there exist 0_1 such that, for each a in S , $a - 0_1 = a$ as well as $a - 0 = a$. Then $0 = 0 - 0_1 = (0 - 0_1) - (0_1 - 0_1) =$ (by (1.)) $(0_1 - 0_1) - (0_1 - 0) = 0_1 - 0_1 = 0_1$ so $0 = 0_1$ and 0 is unique.

Definition 2: If a is in S then $-a$ is defined to be $0 - a$.

Theorem 2: $-(a - b) = b - a$ for all a, b in S .

Proof: $-(a - b) = 0 - (a - b) = (0 - 0) - (a - b) = (b - 0) - (a - 0) = b - a$.

Corollary 1: $-0 = 0$, by letting $a = b = 0$.

Corollary 2: $-(-b) = b$ for all b in S , by letting $a = 0$.

Theorem 3: $a - b = a - c$ implies $b = c$ (cancellation on the left).

Proof: $b - c = (b - c) - 0 = (b - c) - (a - a) = (a - c) - (a - b) = (a - c) - (a - c) = 0$ so $b - c = 0$ and $b = c$.

Corollary: $-b = -c$ implies $b = c$, by setting $a = 0$.

Theorem 4: $a - b = c - b$ implies $a = c$ (cancellation on the right).

Proof: $a - c = -(c - a) = (b - b) - (c - a) = (a - b) - (c - b) = 0$ so $a = c$.

Definition 3: $a + b = a - (-b)$ for all a, b in S .

Since $-$ is a binary operation on S then so is $+$.

Theorem 5: $a + 0 = a$ for all a in S since $a + 0 = a - (-0) = a - 0 = a$.

Theorem 6: $a + -a = 0$ for all a in S since $a + -a = a - (-(-a)) = a - a = 0$.

Theorem 7: $+$ is associative

Proof: $(a + b) + c = (a + b) - (-c) = (a - (-b)) - ((-c) - 0) = (0 - (-b)) - ((-c) - a) = -(-b) - ((-c) - a) = b - ((-c) - a) = (b - 0) - ((-c) - a) = (a - 0) - ((-c) - b) = a - (-(b - (-c))) = a - (-(b + c)) = a + (b + c)$.

Theorem 8: $+$ is commutative.

Proof: $a + b = a - (-b) = (a - 0) - (0 - b) = (b - 0) - (0 - a) = b - (-a) = b + a$

Corollary: using Theorems 5 and 6: $0 + a = a$ and $-a + a = 0$ for all a in S .

As a consequence of the above:

Theorem 9: $(S, +)$ is an abelian group.

Note: Fields can be constructed similarly using a division function $\div$ from $S \times (S - \{0\})$ to S satisfying $(a \div b) \div (c \div d) = (d \div b) \div (c \div a)$ and introducing a unity 1 with $a \div 1 = a$ and $a \div b = 1$ if and only if $a = b \neq 0$. The inverse of a is $a^{-1} = 1 \div a$ and multiplication is defined as $a \times b = a \div b^{-1}$.

In any abelian group $(G, \circ)$ subtraction can be defined by $a - b = a \circ b^{-1}$ and it is readily seen that $(a - b) - (c - d) = (a \circ b^{-1}) \circ (c \circ d^{-1})^{-1} = (d \circ b^{-1}) \circ (c \circ a^{-1})^{-1} = (d - b) - (c - a)$ for all elements a, b, c and d in G . Also, if the identity in $(G, \circ)$ is denoted by 0, then $a - 0 = a \circ 0^{-1} = a$ and $a - b = a \circ b^{-1} = 0$ if and only if $a = b$. Thus any abelian group must be a subtractive groupoid. On the other hand, this paper has shown that, given a subtractive groupoid, an abelian group is always produced.

Therefore abelian groups are completely characterized as subtractive groupoids. Similarly, if division axioms are included then a complete characterization of fields is obtained.

Although $(S, -)$ itself is not a group it contains a group (with respect to $-$) with an interesting connection to the $(S, +)$ group of this paper.

Theorem 10: Let $(S, -)$ be a subtractive groupoid and A be the subset of all elements a such that $a = -a$. Then $(A, -)$ is a group contained in $(S, -)$.

Proof:

(1.) $-$ is associative on A since, with a, b, c in A and using the easily shown identities $(b - c) - c = b$ and $a - (a - b) = b$, $((a - b) - c) - (a - (b - c)) = ((b - c) - c) - (a - (a - b)) = b - b = 0$ so $(a - b) - c = a - (b - c)$.

(2.) A is closed with respect to $-$ since, with a and b both in A and using Theorem 2 and associativity from part (1.) above, $(a - b) -$

$(-(a - b)) = (a - b) - (b - a) = ((a - b) - b) - a = (a - (b - b)) - a = (a - 0) - a = a - a = 0$ so $a - b = -(a - b)$ and thus $a - b$ is in A .

(3.) 0 is the two sided identity since $0 - a = -a = a$ and $a - 0 = a$, and

(4.) inverses exist since $a - (-a) = a - a = 0$ and $(-a) - a = a - a = 0$.

Corollary: The subtractive groupoid $(S, -)$ is a group if $a = -a$ for all a in S .

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GENERAL NOTES

COELOMIC HELMINTHS IN THE SPECKLED RACER,
DRYMOBIUS MARGARITIFERUS (SERPENTES: COLUBRIDAE)
FROM CENTRAL AMERICA**Stephen R. Goldberg and Charles R. Bursey**

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The speckled racer, *Drymobius margaritiferus*, occurs from southern Texas on the Atlantic coast and southern Sonora, Mexico on the Pacific coast, through Central America and into South America along the Caribbean coast of Colombia (Wilson 1974). To the authors' knowledge there is one other report of helminths in *D. margaritiferus* (Goldberg & Bursey 2004a). The purpose of this note is to report larval spiny headed worms and larval nematodes in *D. margaritiferus*.

A total of 49 *D. margaritiferus* from Central America deposited in the Natural History Museum of Los Angeles (LACM), Los Angeles, California were examined for coelomic helminths. Forty-five snakes were from Costa Rica, three from Guatemala and one from Nicaragua. Snakes were originally preserved in 10% formalin and were stored in 70% ethanol. A mid-ventral incision was made in the body wall, and organ surfaces were visually checked for helminths. Helminths were removed and identified from temporary mounts in undiluted glycerol.

Found were two species of Nematoda: third stage larvae of *Ophidascaris* sp. and larvae in cysts of *Porrocaecum* sp. and one species of Acanthocephala: an oligacanthorhynchid cystacanth. Number of helminths, prevalence (infected snake/number snakes examined X 100), location by province and museum numbers are in Table 1. Selected helminths were placed in vials of 70% ethanol and deposited in the United States National Parasite Collection, Beltsville, Maryland: *Ophidascaris* sp. (USNPC 95053); *Porrocaecum* sp. (USNPC 95054); oligacanthorhynchid cystacanth (USNPC 95055).

Table 1. Prevalence and number of coelomic helminths in *Drymobius margaritiferus* from Central America.

Helminth	Prevalence	LACM Number	Location by Province	Number of Helminths
Nematoda				
<i>Ophidascaris</i> sp.	1/49 (2%)	67650	León, Nicaragua	3
<i>Porrocaecum</i> sp.	3/49 (6%)	150576	Cartago, Costa Rica	1
		150604	Cartago, Costa Rica	3
		150577	Guanacaste, Costa Rica	2
Acanthocephala				
cystacanth	1/49 (2%)	150557	Guanacaste, Costa Rica	1

Species of *Ophidascaris* are parasites of the digestive tract of snakes and lizards (Ash & Beaver 1963). In a revision of *Ophidascaris*, Sprent (1988) suggested that only two species, *O. arndti* in crotalines and colubrids and *O. obconica* in colubrids, occur in Central and South America. Because no adults were found, specimens were not assigned to a species. Walton (1937) found larvae of *O. labiatopapillosa* (a North American species) encysted in the stomach wall, mesentery and muscles of frogs. Since *D. margaritiferus* is known to eat frogs (Meyer 1966; Tennant 1984; Conant & Collins 1998), it is conceivable that they acquire *Ophidascaris* sp. by eating infected frogs.

Species of *Porrocaecum* are parasites of the intestines of birds; earthworms serve as intermediate hosts and small mammals that consume earthworms may serve as paratenic (= transport) hosts (Anderson 2000). Because species of *Porrocaecum* do not mature in snakes and because these larvae occurred in cysts, the authors believe snakes may also serve as paratenic hosts. Larvae of *Porrocaecum* are common in Central American snakes and have been reported in eight Costa Rican species (Goldberg & Bursey 2004b).

Acanthocephalans require at least two hosts in the life cycle; arthropods are the usual intermediate hosts in which the infective

stage, the cystacanth, develops (Nickol 1985). When eaten by the definitive host, the cystacanth excysts and develops to maturity in the digestive tract. In paratenic hosts like amphibians and reptiles, the cystacanth does not develop to maturity but migrates from the digestive tract into the coelomic cavity and encysts in mesenteries. Oligacanthorhynchid cystacanths have been reported from 12 Costa Rican snake species (Goldberg & Bursey, 2004b). *Drymobius margaritiferus* represents a new host record for all three helminth species found.

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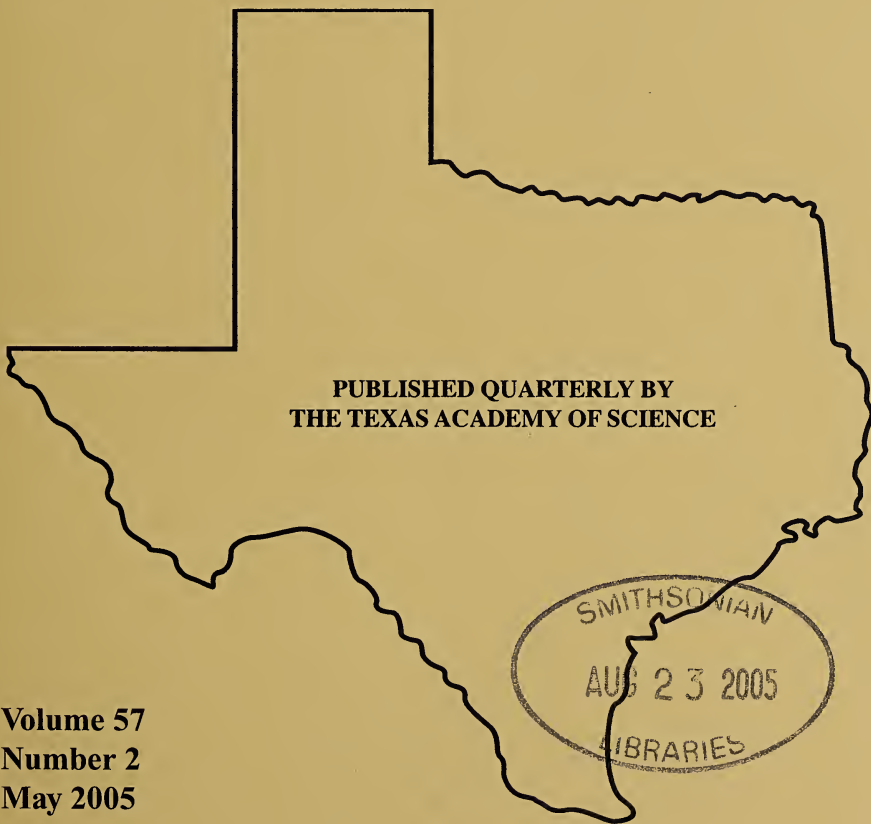


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A COMPUTER SIMULATION AND EVALUATION OF GROUNDWATER RESOURCES IN THE EVANGELINE AQUIFER IN THE AREA OF KLEBERG COUNTY, TEXAS

Alonzo Galvan Arredondo and William F. Thomann

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4301 Broadway, San Antonio, Texas 78209*

Abstract.—A computer simulation of groundwater flow in the Evangeline Aquifer was conducted to determine future groundwater availability within a 5776 square mile (14,960 km²) area southwest of Corpus Christi, Texas. This aquifer is a major source of fresh water for the region, especially in the Kingsville and surrounding areas that rely on the aquifer for municipal, agricultural, industrial, and domestic use. A three-dimensional groundwater model simulating fluid flow within the study area shows maximum drawdown in the Kingsville area based on low to high projected pumping estimates. These results are very similar to an earlier 1985 USGS study of computed potentiometric surface for the area. Although the Kingsville Dome *in situ* leach uranium mine is currently in restoration phase of operation, the model shows, for the period 1988 to 2020, that groundwater withdrawals of 83.0 acre-ft/year ($10.2 \times 10^3 \text{ m}^3/\text{year}$ or $3.24 \times 10^{-3} \text{ m}^3/\text{s}$) and 41.5 acre-ft/year ($51.2 \times 10^3 \text{ m}^3/\text{year}$ or $1.62 \times 10^{-3} \text{ m}^3/\text{s}$) from uranium mining operations will contribute 5.1 ft (1.6 m) and 2.6 ft (0.8 m) of drawdown respectively to the potentiometric surface at the mine area. Thus, a future startup and extraction of groundwater for uranium operations at previous rates will not adversely affect the levels of the water table in the Kleberg County area. Additionally, a discrepancy with the results of a computed potentiometric surface in the 1985 USGS study for the low estimates of projected pumping may be due to errors in data input or excessive pumpage used in the computer simulation.

The availability of freshwater from the Evangeline aquifer (Goliad Formation) in the Kingsville area (population 25,500), southwest of Corpus Christi, Texas is the focus of this hydrogeologic study involving computer simulation of groundwater flow (Figure 1). A previous study was conducted by Groschen (1985) for the United States Geological Survey in cooperation with the Coastal Bend Council of Governments. Groschen's study involved a computer simulation of groundwater flow and solute transport in the Evangeline area of approximately 5776 sq. miles (14,960 km²) and was conducted to determine the potential degradation of groundwater from cross-formational flow (leakage) during intensive pumping.

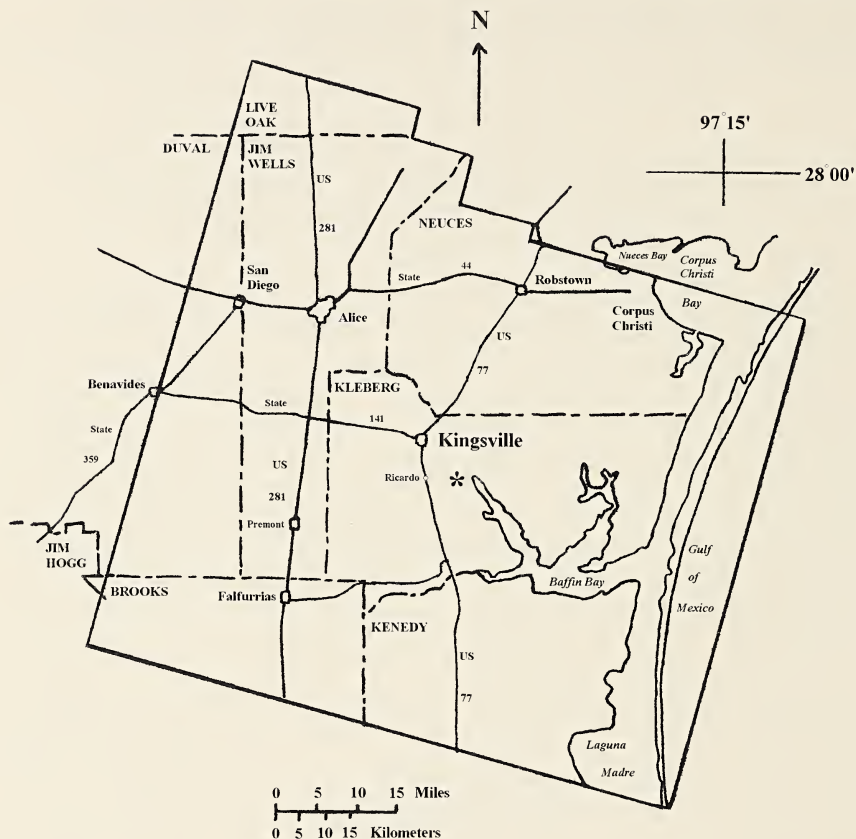


Figure 1. Location map of study area (modified after Groschen 1985). The outer solid black line is the boundary of the modeled area. The asterisk southeast of Kingsville represents the location of the Uranium Resources Incorporated *in situ* leach uranium mine.

The present investigation compares the results of fluid flow simulations from Groschen's (1985) work and similar hydrogeologic data from the United States Geological Survey to data from a more recent simulation. A previous study of the geology and uranium mineralization of the Goliad Formation within the Kingsville Dome area of south Texas has been described by Arredondo (1991) and Arredondo & Thomann (1996). Investigations of the geohydrology, water chemistry, and numerical groundwater modeling of the regional Gulf Coast Aquifer (which includes the Evangeline) can be found in the 2001 Coastal Bend Regional Water Plan (CBWP) and the 2002

Draft Report by Waterstone to the Texas Water Development Board (TWDB).

STUDY AREA

Hydrogeology of the Goliad Formation.—The Goliad Formation is within the Evangeline Aquifer, a major fresh water source in the Texas Gulf Coast (Knape 1984; CBRWP 2001) supplying water for municipal, industrial, and agricultural use. The Evangeline Aquifer is one of four aquifer formations (Catahoula, Jasper, Evangeline, Chocot) of the Gulf Coast Aquifer System that extends from northern Mexico to Florida (CBRWP 2001). A climatic atlas published by the Texas Water Development Board shows the study area is subhumid to subarid, the average annual precipitation from 1951-1980 is 27 inches (69 cm) and the average gross lake surface evaporation rate for the period of 1950-1979 is 65 inches (165 cm) (Larkin & Bomar 1983).

The Evangeline aquifer is both a confined and an unconfined aquifer. The unconfined part of the aquifer is approximately 22 miles (35 km) west of the city of Kingsville where the Goliad Formation crops out and forms a belt of sediments which parallel the coastline (Figure 2). The confined portion of the aquifer exists below a low-relief surface to the southeast of where the Goliad crops out. Closer to the Texas coastline, the Goliad sands of the Evangeline aquifer are about 400 ft (122 m) thick, and lie at depths of approximately 500 to 2000 ft (152 to 610 m) below the ground surface.

Recharge occurs at the unconfined portion of the Evangeline aquifer in Jim Wells and the west-central area of Duval County where the Goliad Formation crops out. Recharge may also occur by vertical leakage during periods of high withdrawals as pressures in the confined portion of the Evangeline are reduced through intensive pumping to allow downward leakage from the overlying Chicot aquifer through leaky clays. Groschen's (1985) estimations of the effective recharge required to maintain the predevelopment hydraulic gradients in the Evangeline are 0.23 percent (0.06 in. per year or 0.15 cm per year) of the average annual precipitation of 26 inches (66.0 cm) for the study area.

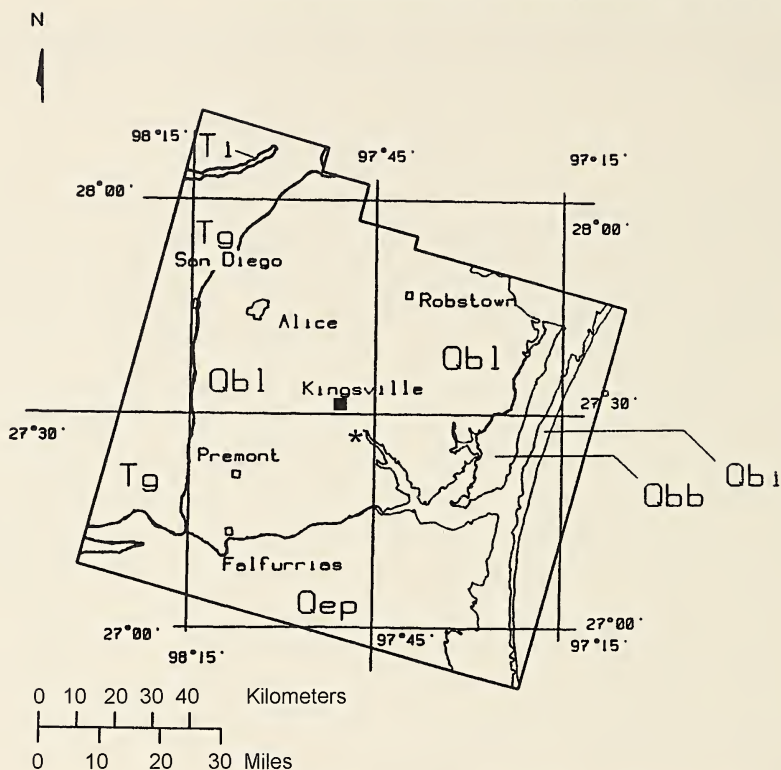


Figure 2. Generalized geologic map of the study area (modified after Groschen 1985). The asterisk southeast of Kingsville represents the location of the Uranium Resources Incorporated (URI) *in situ* leach uranium mine. Qbi – barrier island deposits, Qep – eolian plain deposits, Qbb – barrier island and beach deposits, Qb1 – Beaumont clay and Lissie Formation, Tg – Goliad Formation, Ti – Lagarto clay.

Prior to development of the groundwater resources, groundwater flowed in a southeast direction towards the Texas coastline. However, extensive pumping of groundwater has altered the direction of the groundwater flowpaths with the formation of a cone of depression at the center of the study area. Rettman (1983) measured the water levels in the Evangeline in the Kingsville area during 1982 and found a large cone of depression in the potentiometric surface which occurs below Kingsville. This cone of depression formed as a result of high water withdrawals for municipal and industrial usage. Prior to 1907, and perhaps as recently as 1928, water wells in the Goliad were flowing artesian in western and southern Kleberg County (Livingston &

Bridges 1936; J. Arredondo, pers. comm.). In 1933, hydraulic pressure in the Evangeline aquifer had decreased such that only wells in west-central Kleberg County (west of Riviera and south of the city of Kingsville) were flowing artesian. Inspection of maps of the 1982 potentiometric surface prepared by Rettman (1983) shows that the capacity for water in the Evangeline aquifer to flow freely above the surface is greatest in east Kenedy and Kleberg counties along the shores of the Laguna Madre. All remaining water wells in Kleberg County west of Laguna Madre are non-flowing artesian.

Hydrochemistry.—The aquifer sands within the Goliad contain interstitial water of the meteoric flow regime. Chemical analysis of major constituents in Goliad Formation groundwater from the Texas Water Development Board data base shows that groundwaters sampled from the period of 1959 to 1984 are fresh to brackish and average 997 milligrams per liter of total dissolved solids. Chloride concentrations in the Evangeline Aquifer increase in an easterly direction with progressively greater depth of the aquifer (Shafer & Baker 1973; CBRWP 2001). Higher concentrations of chloride are attributed to zones of fault-related discharge, and typically increase basinward where marine sediments with saline connate water are dominant.

METHODS AND MATERIALS

Hydrogeological analysis.—The specific objectives of this study were to: (1) simulate the potentiometric surfaces computed by Groschen (1985); (2) determine the effects of groundwater withdrawals from uranium mining operations on the potentiometric surface of the Evangeline aquifer; (3) test several boundary conditions used by Groschen (1985) in a 38-row by 38-column grid model and determine the appropriate use of the boundary conditions; and (4) determine if there may be any significant dewatering of the Evangeline Aquifer due to *in situ* leach mining operations at the Kingsville Dome plant (currently in restoration phase).

Calibration of the fluid flow model in this study utilizes Groschen's (1985) data for steady-state and transient-state flow simulations for the years 1901 through 1982. The potentiometric surface

as defined by Groschen (1985) is the elevation at which groundwater levels would stand in tightly cased wells. Hydraulic heads were mapped and potentiometric surfaces were contoured with SURFER Version 4.00 (Golden Software Inc. 1989) contouring and mapping software. This surface was mapped with the Kriging gridding technique at contour intervals of 25 ft (7.6 m) to allow comparison with Groschen's (1985) results. The 25 foot interval is a commonly used contour interval of most hydrogeologic maps in this study area.

Data collection.—Data from the Texas Water Development Board's data bank of observation wells in Kleberg, Jim Wells, Nueces, Kenedy, and Brooks counties, the U.S. Geological Survey, Texas state reports, and King Ranch archives were utilized for the verification of aquifer heads. Historical information was gathered from discussions with area scientists and local citizens who were knowledgeable of the history of groundwater use.

Data analysis.—A quasi three-dimensional finite difference model was used to simulate recharge, hydraulic conductivity, storativity, multiple pumping wells, aquifer sand thickness, aquifer heads, and leakage from an overlying aquifer. Design of the aquifer model was similar to Groschen's (1985) U.S.G.S. study of the Evangeline aquifer. Model simulations were performed to determine the sensitivity and accuracy of head calculation with respect to boundary conditions designated as no-flow in Groschen's (1985) model. The methods and techniques which are used to calibrate an aquifer model are not presented because the aquifer model was calibrated using Groschen's (1985) data. An analysis was undertaken to determine the sensitivity of the calibrated model to uncertainties in the data, of the aquifer properties, and the assumptions of the model. This sensitivity analysis was employed during the steady-state and transient-state simulations to determine the appropriate use of the no-flow boundary conditions by the United States Geological Survey in a groundwater simulation (Franke et al. 1987). The elevations of the potentiometric surfaces of the one-layer three-dimensional fluid flow aquifer simulations were compared to those results by Groschen (1985).

Simulation of the Evangeline Aquifer.—The fluid flow for the

Evangeline Aquifer in the study area was modeled to examine the following: (1) the transient-state effects on the potentiometric surface for the years 1983-2020; (2) the effects that potential pumping from uranium mining operations at the Kingsville Dome would have on the groundwater resources in the future; and (3) the results of a sensitivity analysis on Groschen's (1985), no-flow boundary conditions on the east and south sides of the modeled area.

Groschen's (1985) simulation strategy was to accomplish the following: (1) identify a period when the aquifer was in equilibrium, and use aquifer heads as the initial aquifer potentiometric surface; (2) perform a steady-state simulation to adjust hydrologic input and parameters until computed heads matched the field heads for the period of equilibrium; (3) use the steady-state computed heads as the initial potentiometric surface; and (4) model all stresses which had occurred on the aquifer, as well as project stresses to a future period.

Conceptual model.—The Evangeline and the Chicot aquifers were modeled using Groschen's (1985) conceptual model which describes the actual physical boundaries of the aquifer flow system (Figure 3). The conceptual model consists of the confined and unconfined Evangeline aquifer flow system which exhibits heterogeneous and anisotropic conditions. The Evangeline is confined where the Beaumont and Lissie Formations overlie the Goliad Formation, and is unconfined aquifer in the western part of the study area where the sands of the Goliad Formation crop out at the surface. The aquifer dips to the southeast below the Gulf of Mexico where the freshwater/salt-water interface occurs several miles east of Padre Island. The Evangeline aquifer also extends beyond the southern borders of the modeled area towards the Rio Grande River, and to the north beyond the study area.

The Chicot aquifer is an overlying unit which is included within the Beaumont clays and the low permeability Lissie sands (C. Bartels pers. comm.). The Chicot aquifer has permeable sandy units that are approximately 30 to 100 ft (9.1 to 30.5 m) thick, and clay lenses of low permeability which confine the aquifer.

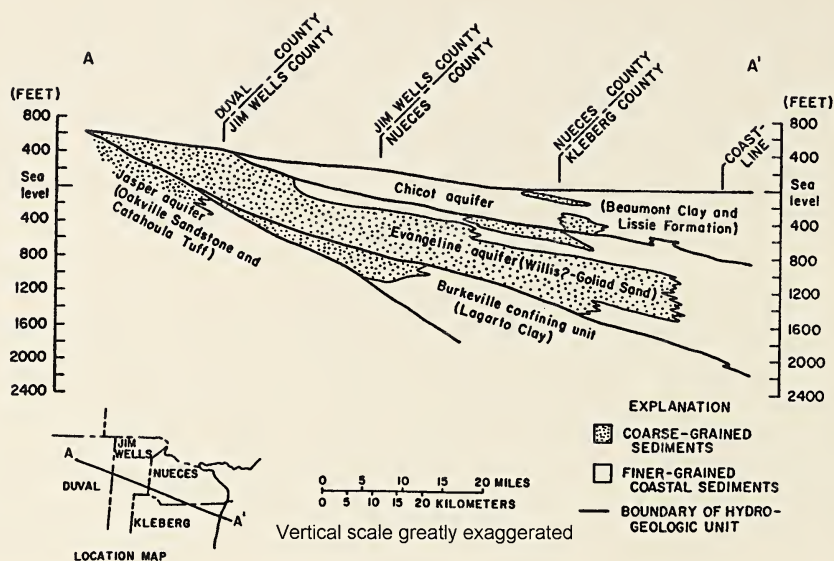


Figure 3. Generalized hydrogeologic cross-section of the Evangeline Aquifer system used as the conceptual aquifer model (modified after Groschen 1985).

Mathematical model.—The mathematical model is a numerical version of the conceptual model and usually much simpler in design than an exact model of the aquifer. The numerical groundwater model was developed with MODFLOW - *A Modular Three-Dimensional Finite-Difference Groundwater Flow Model* (Version 1634) by MacDonald & Harbaugh (1988). The flow model calculates hydraulic heads, and determines groundwater flow in a quasi three dimensional space using the block centered finite difference approach. An iterative solution technique using the Strongly Implicit Procedure (SIP) was used to solve the finite-difference equations. A three dimensional simulation was performed for a one-layer by 38-row by 38-column grid. The model was specified for constant head and no-flow boundary conditions, horizontal and vertical hydraulic conductivities, aquifer thicknesses, elevations of aquifer layers, pumping cells, storativities for each block cell, and source terms for discharge, recharge, and wells. Groschen's (1985) simulation grid for the discrete-modeled conceptual aquifer system was applied for the study area (Figure 4). The boundary conditions of the aquifer are those assigned by

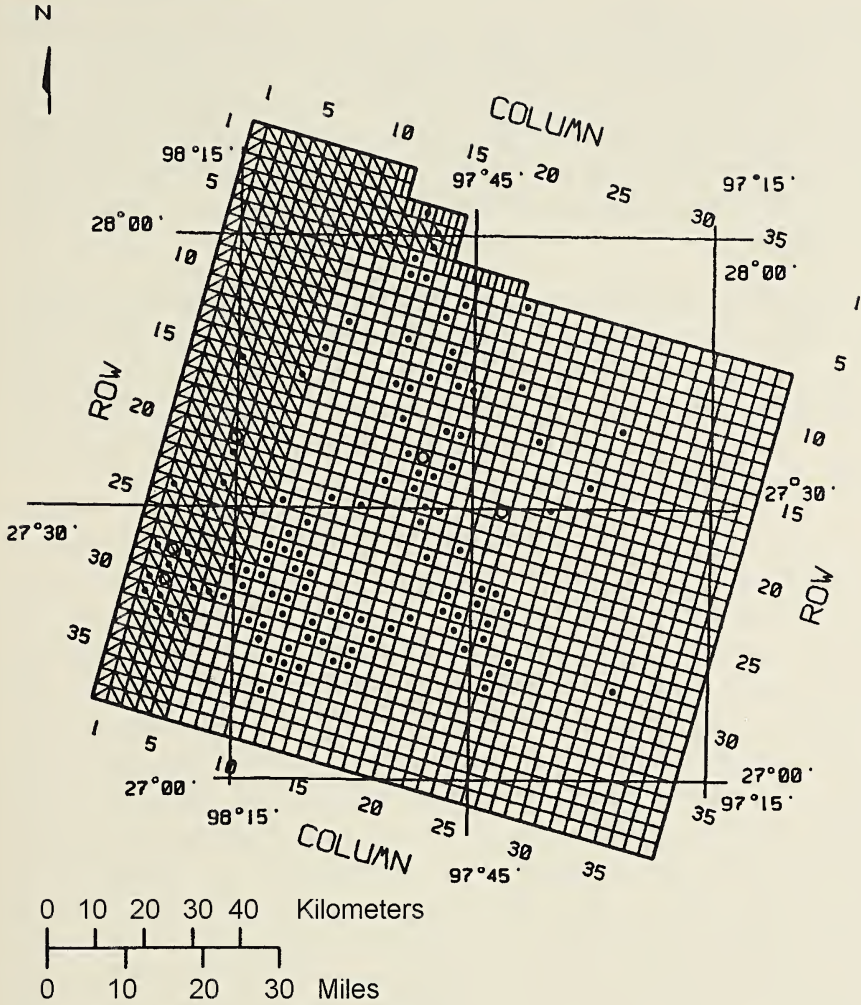


Figure 4. Simulation grid for the discretized conceptual aquifer at the study area (modified after Groschen 1985). Open square – confined aquifer cell, upper left-lower right diagonal square – unconfined aquifer square, centered dot in square – pumping well, vertical line in square – river cell, upper right-lower left diagonal square – constant head cell, open circle in square – observation well, outer solid line – no flow boundary.

Groschen (1985) in which the west boundary was modeled with a constant head to simulate recharge from infiltration of surface water. The north model boundary was designated as a no-flow boundary because it corresponds with the regional aquifer discharge area at the

Nueces River and Nueces Bay. The southern and eastern boundaries were designated as no-flow boundaries. The eastern no-flow boundary was designated as a fixed stream surface (no-flow) boundary because the freshwater/saltwater interface was considered fixed under stress. The southern boundary was designated as a no-flow boundary but, according to Groschen (1985), is not valid for the transient-state simulation.

The Lissie sand (of the Chicot aquifer) acts as a confined aquifer in the URI mine area, but very little regional hydrologic data for the Chicot is available. Therefore, a Cauchy boundary condition (mixed boundary) (Franke et al. 1987) was used to simulate a source from the Chicot aquifer and provide head-dependent leakance across the overlying Chicot aquifer into the Evangeline.

Steady-state flow simulation.—The steady state simulation was performed to simulate the initial potentiometric surface, and the steady-state model is calibrated to Groschen's 1901-1982 data. This initial surface was computed by using Groschen's (1985) calibrated initial aquifer head and confining layer head arrays for the steady-state condition. Groschen's (1985) steady-state simulation required adjustments of input data and hydrologic parameters for the model calibration. The water balance was used to determine when the aquifer system was in a steady-state flow condition. Groschen (1985) used the computed steady-state heads as initial heads for the transient-state simulations. The amount of water which flows through Groschen's (1985) predevelopment aquifer model is $7.0 \text{ ft}^3/\text{s}$ ($0.20 \text{ m}^3/\text{s}$), whereas the amount of water which flows through Arredondo's (1991) predevelopment aquifer model using MODFLOW is $5.7 \text{ ft}^3/\text{s}$ ($0.16 \text{ m}^3/\text{s}$). The volume of water which flows into and out of Arredondo's (1991) pre-adjusted steady-state aquifer is $9.0 \times 10^9 \text{ ft}^3$ ($2.74 \times 10^9 \text{ m}^3$).

Transient-state flow simulation.—Transient-state flow simulations were conducted for the periods of 1901 to 2020. The steady-state head configuration was used as the initial conditions for the transient flow simulations. Calibrated hydrologic data used for the computer model is from Groschen (1985). During the calibration phase, Groschen (1985) matched the computed heads to Rettman's (1983) observed field heads to an error $\pm 40 \text{ ft}$ (12.2 m). The rates of with-

drawal from pumpage, as well as low and high pumping rates, simulated in this report are those from Groschen (1985). Withdrawals of 90.4 ft³/s (2.6 m³/s) for the entire model were used during the calibration period. The low estimate of withdrawal for the projected pumping period of 1983-2020 was 127.9 ft³/s (3.6 m³/s), and the high estimate of withdrawal for the projected pumping period of 1983-2020 was 223.7 ft³/s (6.3 m³/s). Computer simulations were also conducted to determine the effects from the mining uranium on the potentiometric surface for high withdrawals at 9625.0 ft³/day (272.5 m³/day), and for low withdrawals at 4812.5 ft³/day (136.3 m³/day).

Sensitivity analysis of the aquifer model.—A sensitivity analysis was conducted to determine the response of the simulation model to the use of no-flow boundary conditions in the eastern and southern borders. Both the eastern and southern boundaries were selected because as Groschen (1985) stated, there were no corresponding physical boundaries. The no-flow boundaries assigned by Groschen (1985) in his 38-row by 38-column grid at the eastern and southern edges were tested by expanding the model grid to 48 rows by 48 columns for steady-state and transient-state simulations. The modeled area was expanded to include 10 cells (20 miles) to the east and 10 cells to the south. Input data for the aquifer cells in rows 39 to 48 and cells in columns 39 to 48 were identical to that of row 38 and column 38 respectively. Simulations were conducted for Groschen's (1985) calibration period of 1901-1982, and the period of 1983-2020 with the high estimate of projected pumping. Contours of the potentiometric surfaces from simulations of the 38-row by 38-column grid were compared to those of the 48-row by 48-column grid. The differences in the potentiometric surfaces of the 38-row by 38-column grids and the 48-row by 48-column grids were calculated and mapped as the difference in drawdown, and as the percent difference of the total drawdown.

RESULTS OF SIMULATIONS

Results of the simulation with the data for the calibration period (1901 to 1982) in Figure 4 using 48 by 48 simulation cells are similar to Groschen's (1985). Table 1 summarizes the modeled withdraw from the Evangeline Aquifer, Table 2 summarizes the modeled inflow

Table 1. Summary of modeled water withdrawals from the Evangeline Aquifer.

Period	Mine Production Municipal Uses ft ³ /s (m ³ /s)	Agricultural, Industrial, and Municipal Uses ft ³ /s (m ³ /s)	Leakage ft ³ /s (m ³ /s)	Storage ft ³ /s (m ³ /s)	Total Withdraw ft ³ /s(m ³ /s)
1901-1982	0.0	13.24 (0.37)	1.43 (0.04)	2.08 (0.06)	16.76 (0.47)
Low Pumping Estimates of Projected Mining					
1901-1990	<0.01	15.18 (0.43)	1.31 (0.04)	1.93 (0.05)	18.42 (0.52)
1901-2000	<0.01	18.06 (0.51)	1.18 (0.03)	1.75 (0.05)	21.00 (0.60)
1901-2010	0.01 (0.0003)	21.12 (0.60)	1.07 (0.03)	1.60 (0.04)	23.81 (0.67)
1901-2020	0.02 (0.0004)	24.36 (0.69)	0.98 (0.03)	1.49 (0.04)	26.85 (0.76)
High Pumping Estimates of Projected Mining					
1901-1990	<0.01	15.18 (0.43)	1.31 (0.04)	1.93 (0.05)	18.42 (0.52)
1901-2000	0.01 (0.0004)	18.06 (0.51)	1.18 (0.03)	1.75 (0.05)	21.01 (0.60)
1901-2010	0.02 (0.0007)	21.12 (0.60)	1.07 (0.03)	1.60 (0.04)	23.82 (0.68)
1901-2020	0.03 (0.0009)	24.36 (0.69)	0.98 (0.03)	1.49 (0.04)	26.87 (0.76)

The rates for the agricultural, industrial, and municipal uses are from Groschen (1985). The pumping projections for the agricultural, industrial, and municipal uses are the high estimates of the Texas Water Development Board and the Bureau of Reclamation as reported by Groschen (1985).

Low mine projection estimate is 5.57×10^{-2} ft³/s (1.58×10^{-3} m³/s) and high estimate is 1.14×10^{-2} ft³/s (3.16×10^{-3} m³/s).

Table 2. Summary of modeled water inflow into the Evangeline Aquifer.

Period	Mine Production ft ³ /s (m ³ /s)	Leakage ft ³ /s (m ³ /s)	Flow From Infiltration ft ³ /s (m ³ /s)	Storage ft ³ /s (m ³ /s)	Total Inflow ft ³ /s (m ³ /s)
Calibration Period					
1901-1982	0.0	7.26 (0.21)	6.80 (0.19)	2.70 (0.08)	16.76 (0.48)
Low Pumping Estimates of Projected Mining					
1901-2000	<0.01	10.30 (0.29)	6.89 (0.20)	3.82 (0.11)	21.00 (0.60)
1901-2010	0.01 (0.0003)	12.31 (0.35)	6.97 (0.20)	4.53 (0.13)	23.81 (0.67)
1901-2020	0.02 (0.0004)	14.56 (0.41)	7.07 (0.20)	5.24 (0.15)	26.85 (0.76)
High Pumping Estimates of Projected Mining					
1901-2000	0.01 (0.0004)	10.30 (0.29)	6.89 (0.20)	3.82 (0.11)	21.01 (0.60)
1901-2010	0.02 (0.0007)	12.32 (0.35)	6.97 (0.20)	3.82 (0.11)	23.82 (0.68)
1901-2020	0.03 (0.0009)	14.56 (0.41)	7.07 (0.20)	5.24 (0.15)	26.87 (0.76)

Constant head boundaries are used for flow from infiltration. Low mine projection estimate is 5.57×10^{-2} ft³/s (1.58×10^{-3} m³/s) and high estimate is 11.14×10^{-2} ft³/s.

into the Evangeline Aquifer, and Table 3 lists the summary and results of the computer simulations and sensitivity analysis. Maximum draw-down occurs in the area surrounding the City of Kingsville, where the elevation of heads range from -184 to -150 ft (-56.0 to -45.7 m). Comparison of the computed potentiometric surface to Groschen's (1985) results, simulated with the use of Konikow & Bredehoeft's (1987) Method of Characteristics (MOC) simulation model, reveals no significant differences with the exception of increased drawdown at the eastern no-flow boundary (the zero elevation contour is closer to the eastern no-flow boundary). Differences in elevations between these results and Groschen's (1985) are approximately 4 ft (1.2 m) at the eastern boundary.

Comparison of the computed potentiometric surface with the low estimates of projected (1983 to 2020) pumping for Groschen's (1985) computed potentiometric surface reveals that aquifer simulations using MODFLOW are locally more sensitive to reductions of the pumping rates than Groschen's (1985) computed surface with MOC. The aquifer model using MODFLOW responded to the reduced rates of withdrawal by computing a potentiometric surface which has an elevation of approximately -47.8 ft (-14.6 m) for the Kingsville area. The elevation of Groschen's (1985) computed potentiometric surface presented for the Kingsville area is approximately -250 ft (-76.2 m). Differences in heads of the potentiometric surface with the low estimates of projected pumping in this study are approximately 202 ft (61.6 m) higher than Groschen's (1985) computed potentiometric surface with MOC.

Results of the computer simulation of pumping of the aquifer for the calibration period (1901 to 1982), and for the 1983 to 2020 simulation using high estimates of projected pumping are shown in Figure 5. Maximum drawdown occurs in the City of Kingsville area where the elevation of heads range from -469 to -400 ft (-142.9 to -121.9 m). These results are very similar to Groschen's (1985) computed potentiometric surface.

The Kingsville Dome uranium *in situ* leach mine is currently in a restoration phase but the source of the low and high pumping rates used in this paper are projected from historical pumping rates. The

Table 3. Summary and results of computer simulations and sensitivity analysis for the study area.

1. Simulation of calibration period 1901-1982.

Simulation for this period shows similar results as Groschen's, (1985) computed potentiometric surface. The contour of zero altitude differs with that of Groschen, (1985). Drawdown could be the effect of the eastern no-flow boundary. Heads differ in the City of Kingsville area from approximately -184 to -150 feet (-56.0 to -45.7 meters) below sea level.

2. Simulation of low estimates of projected pumping 1983-2020.

Simulation for this period did not replicate Groschen's, (1985) computed potentiometric surface. Differences in altitude of the potentiometric surface at the City of Kingsville are 202 feet. Altitudes in this simulation are approximately -47.8 to -25 feet (-14.6 to -7.6 meters) below sea level at the City of Kingsville. This simulation shows that Groschen's published withdrawals for this period are not sufficient to replicate his reported results.

3. Simulation of high estimates of projected pumping 1983-2020.

Simulation for this period yields similar results as Groschen's (1985) computed potentiometric surface. Potentiometric surface at the City of Kingsville ranges from -469 to -400 feet (-142.9 to -121.9 meters) below sea level.

4. Simulation of high estimates of projected pumping with low mine production 1983-2020.

Simulation for this period which includes a low estimate (4812 ft³/day or 0.0557 ft³/s) of mining production did not produce significant differences from the simulation of high estimates of projected pumping without mining production (simulation #3). The calculated head at the mine area is 2.6 feet (0.8 meter) lower in altitude.

5. Simulation of high estimates of projected pumping with high mine production 1983-2020.

Simulation for this period with a high estimate (9624 ft³/day or 0.1114 ft³/s) of mining production did not produce significant differences from the simulation of high estimates of projected pumping without mining production (simulation #3). The calculated head at the mine area is 5.1 feet (1.6 meter) lower in altitude.

6. Simulation of calibration period 1901-1982 with simulation grid expanded to 48 by 48 grid.

Simulation for this period produced differences in altitude of the potentiometric surfaces of the 38 by 38 and 48 by 48 grids of approximately 13 feet (4.0 meters), at the southern boundary, to 1 foot (0.3 meter) 7 to 10 miles (11.3 to 16.1 km) south of the City of Kingsville. Maximum differences in altitude at the eastern no-flow boundary are approximately 0.9 feet (0.3 meter).

7. Simulation of high estimates of projected pumping 1983-2020 with simulation grid expanded to 48 by 48 grid.

Simulation for this period produced a potentiometric surfaces for the 48 by 48 grid at the southern no-flow boundary with a difference of 30 feet (9.1 meter), 1 foot (0.3 m) at the southern edge approximately 7 to 10 miles (11.3 to 16.1 km) south of the City of Kingsville. Difference in altitude at the eastern no-flow boundary is approximately 3.7 feet (1.1 meters).

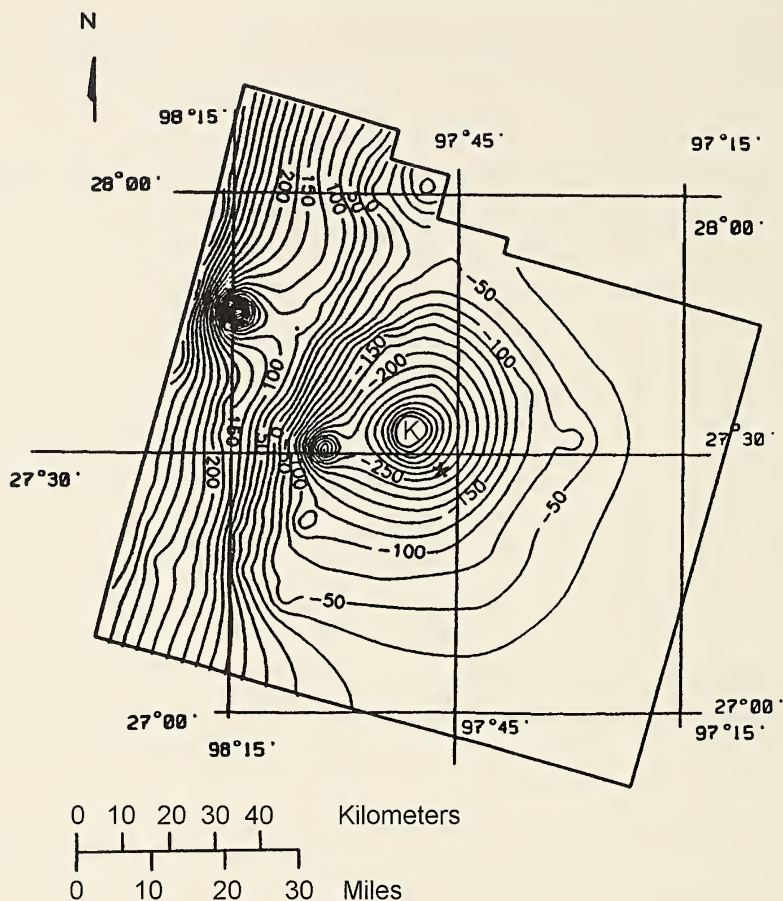


Figure 5. Computed potentiometric surface showing elevations of groundwater with the calibrated data for the period of 1901 to 1982. The letter **K** and asterisk represent the locations of Kingsville and the URI mine, respectively. Potentiometric contour interval – 25 feet (7.6 m).

simulation of pumping of groundwater from the production within the Kingsville Dome uranium mine projected for the period 1988-2020 decreases the elevation of the potentiometric surface by 2.6 ft (0.8 m). Comparisons of the computed potentiometric surface from the high estimate that does not simulate mining with the computed potentiometric surface which does simulate mining do not reveal significant differences in the elevations of those potentiometric surfaces respectively.

Results of the 48-row by 48-column grid sensitivity analysis for

the calibration period are different simulated heads than results with the 38-row by 38-column grid. Generally the elevations of the potentiometric surfaces for the 38-row by 38-column grid are lower than those of the 48-row by 48-column grid respectively. The difference in the elevations of the potentiometric surfaces of the 38-row by 38-column grid and the 48-row by 48-column grid is 13 ft (4.0 m) of drawdown. This difference is attributed to boundary effects from the southern no-flow boundary and the additional volume of water in storage. The contour line representing 1 foot (0.3 m) elevation is approximately 7 to 10 miles (11.3 km to 16.1 km) south of Kingsville. The eastern no-flow boundary does not significantly influence the elevation of the potentiometric surface throughout the eastern portion of the study area.

Results from the sensitivity analysis with the 48-row by 48-column grid for the period of 1983-2020 with the high estimates of projected pumping also show differences in the simulated heads in comparison to results from the 38-row by 38-column grid (Figure 6). The greatest difference in elevation of the potentiometric surfaces of the 38-row by 38-column grid and the 48-row by 48-column grid is approximately 30 ft (9.1 m) of drawdown which occurs at the southern no-flow boundary. The 1 ft (0.3 m) contour line remains approximately 7 to 10 miles (11.3 km to 16.1 km) south of Kingsville but lies closer to the high pumping center west of Kingsville. The eastern no-flow boundary does not greatly influence the elevation of the potentiometric surface in the eastern portion of the study area. Boundary effects from the eastern no-flow boundary range from 1 ft (0.3 m) to approximately 3.7 ft (1.1 m) of drawdown at the eastern edge. The percent of the differences in drawdown of the 38-row by 38-column the 48-row by 48-column grid potentiometric surfaces to the total drawdown of the 48-row by 48-column grid potentiometric surface for the calibration period is presented in Figure 7. The sensitivity analysis supports Groschen's (1985) report which states the eastern boundary can be designated as a no-flow boundary and will not contribute significant boundary effects. The analysis also supports Groschen's (1985) conclusion that the southern boundary is not valid under transient-state conditions. As Groschen (1985) had determined in his sensitivity analysis for two different boundary conditions, the computed potentiometric surface is not significantly different in the area by the designation of two different grid sizes.

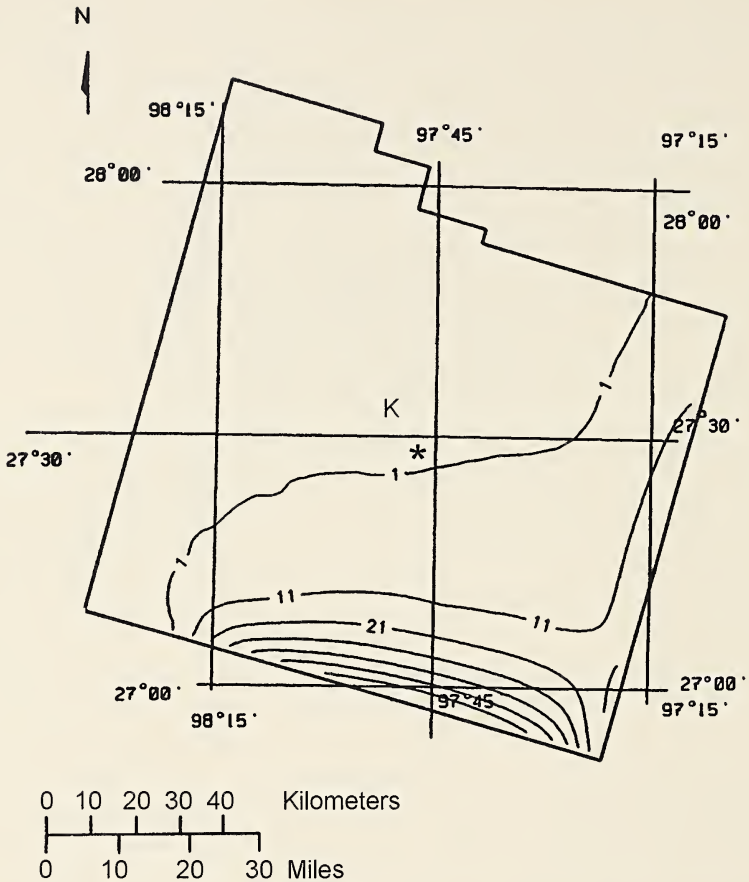


Figure 6. Computed potentiometric surface from the test of the boundary conditions showing elevations of groundwater with the high estimates of projected pumping from 1983 to 2020. The letter **K** and asterisk represent the locations of Kingsville and the URI mine, respectively. Solid lines represent percent contours of the total drawdown from the boundary effects. Contour interval – 10 percent.

The simulations were not an attempt to match the exact levels of the potentiometric surface of the Evangeline aquifer, but rather to obtain the range of effects that pumping would have on the potentiometric surface of the aquifer. Based on the elevation of the top of the aquifer sands of the Goliad Formation, model results indicate that de-watering of the aquifer will not occur in the Kingsville area until the elevation of the potentiometric surface is less than approximately 580 ft (176.8 m) below sea level (Arredondo 1991).

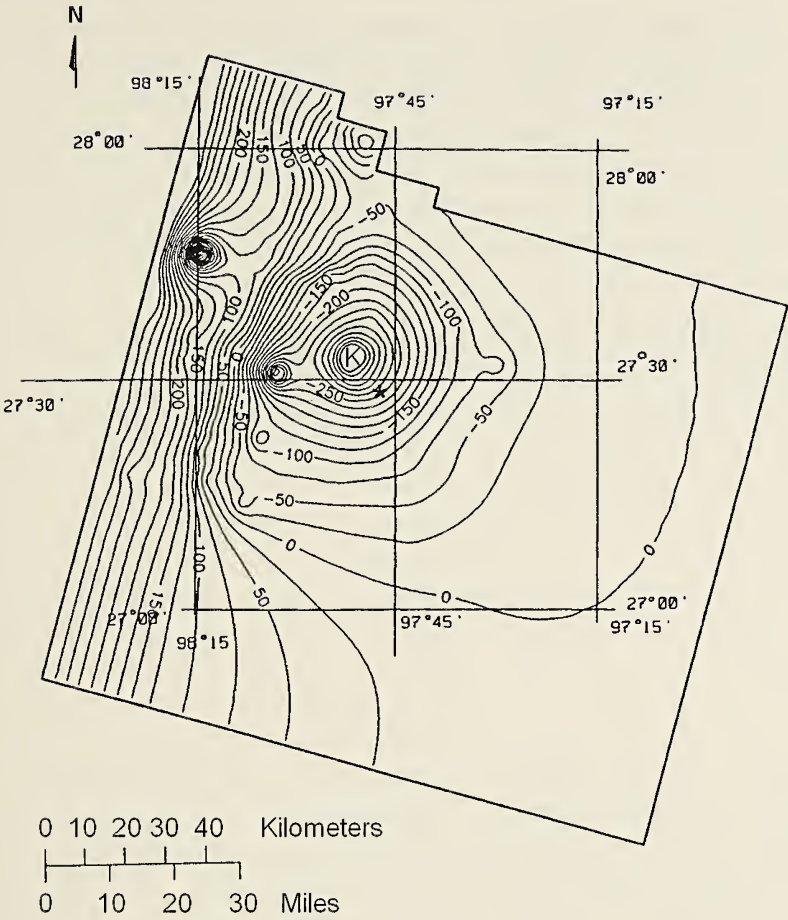


Figure 7. Percent of the differences in drawdown of the 38-row by 38 column grid and the 48-row by 48-column grid potentiometric surfaces to the total drawdown of the 48-row by 48-column grid potentiometric surface with the calibrated data for the period of 1901 to 1982. The letter **K** and asterisk represent the locations of Kingsville and the URI mine, respectively. Potentiometric contour interval – 25 feet (7.6 m).

CONCLUSIONS

Groundwater steady-state and transient-state computer simulations of the Evangeline aquifer using MODFLOW, a 3-dimensional groundwater model yields several results. A fluid flow simulation for the calibration period of 1901-1982 shows that elevations of heads for the Kingsville range from approximately -184 to -150 ft (-56.0 to -

45.7 m) below sea level. A simulation with the low estimates of projected pumping for the period of 1983-2020 yields heads with elevations of approximately -47.8 to -25 ft (-14.6 to -7.6 m) for the Kingsville area, and is 202 ft (61.6 m) higher in elevation than the value computed by Groschen (1985). A simulation with the high estimates of projected pumping for the period 1983-2020 yields heads with elevations which range from -469 to -400 ft (-142.9 to -121.9 m) for the Kingsville area.

The Kingsville Dome *in situ* leach uranium mine has been operating in a restoration phase since 1999 (URI company news release, November 16, 1998), but the following conclusions based on computer simulations, structural geology, and water-table elevations (Arredondo 1991) can be drawn on the hydrogeology of the Kingsville area should mine operations start up again in the near future. Withdrawals of 41.5 acre-ft/year (51.2 by 10^3 m³/year or 1.62 by 10^{-3} m³/s) from mining for the period of 1983-2020 with the high estimates of projected pumping will contribute to 2.6 ft (0.8 m) of additional drawdown at the mine area. Withdrawals of 83 acre-ft/year (102.4 by 10^3 m³/year or 3.24 by 10^{-3} m³/s) from uranium mining operations for the period of 1988-2020 will contribute to 5.1 ft (1.6 m) of additional drawdown of the computed potentiometric surface in the mine area. The high pumping estimates of mining operations will contribute 0.12 percent to the total simulated withdrawals of groundwater. Thus, groundwater withdrawals for uranium operations, if continued at simulated rates, would not adversely affect the levels of the water table in the Kleberg County area.

A sensitivity analysis of the simulation model examining the effects of the southern and eastern no-flow boundaries on the 38-row by 38-column grid shows that 13 ft (4.0 m) of drawdown is expected from the southern no-flow boundary for the calibration period of 1901-1982. Less than 1 ft (0.3 m) of drawdown is attributed to the eastern no-flow boundary on the 38-row by 38-column grid for the calibration period. Approximately 30 ft (9.1 m) of drawdown is expected at the southern no-flow boundary for the period 1983 to 2020 with the high estimates of projected pumping. Projected drawdown at the eastern no-flow boundary on the 38-row by 38-column grid for the same period is approximately 3.7 ft (1.1 m).

De-watering of the aquifer would occur in the Kingsville area when the elevation of the potentiometric surface attains an elevation of less than -580 feet (-176.8 m). However, historical declines in the Kingsville area have ceased with water levels rising due to the city's increasing use of surface water from nearby reservoirs owned by the City of Corpus Christi (Groundwater Conservation District Operations Manual 1999). The discrepancy with the results of a computed potentiometric surface in the U.S.G.S. study (Groschen, 1985) for the low estimates of projected pumping could be due to Groschen's use of excessive pumping rates that exceeded his published low pumping rates. This discrepancy might also be due to incorrect data from original sources or incorrect input into the computer simulation.

The authors make the following recommendations on a future study of groundwater resources in the Kingsville area: (1) audit the pumping rates for several municipalities as well as all other entities with major water use; (2) record the measurements of potentiometric surfaces, and (3) run another computer simulation for comparison with current and past models.

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STRUCTURE OF HISTORIC VEGETATION ON
KERR WILDLIFE MANAGEMENT AREA,
KERR COUNTY, TEXAS

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Abstract.—Witness tree data from original land surveys conducted during 1876-1884 were used to characterize the historic vegetation of a site in the Balcones Canyonlands of the Edwards Plateau. Eight tree species were recorded from the study area by surveyors, with Plateau oak (*Quercus fusiformis*) and Ashe juniper (*Juniperus ashei*) being the most abundant; the largest individuals were of post oak (*Quercus stellata*) and Ashe juniper. Kerr Wildlife Management Area (WMA) was dominated by open grassland (64% of survey points); savanna (15%) and wooded areas (15%) were less common. Grassland has disappeared from the area over the past 120 yr, being replaced by woodland and forest in the contemporary landscape. No association was found between the structure of historic plant communities and ecological site types on Kerr WMA.

Little quantitative information has been published on the historic vegetation of the Edwards Plateau of Texas. Most of the current knowledge of plant communities in the region during the 19th century is based on general observations by travelers and recollections of early settlers (Weniger 1984; Smeins et al. 1997). Official state reports from the 1880s on the vegetation of counties in the Edwards Plateau likewise provide only a general indication of vegetation structure within the region. For example, Spaight (1882) implies that Kerr County, with the exception of a large cedar brake (juniper forest), was mostly savanna, asserting that there were no prairies (grasslands). He found trees to be more abundant along streams. Foster (1889), in contrast, reports that there were at least 10,161 ha of prairie in the county, but concurred that the valleys were timbered. During the 20th century, the consensus was that Kerr County uplands had been dominated by grassland and/or savanna when first settled (Buechner 1944; Weniger 1988; Armstrong et al. 1991; Fuhlendorf et al. 1996).

Ranching of the Kerr County area of the Edwards Plateau initiated changes in vegetation including replacement of tall grasses by shorter species, reduced grass cover, increased woody cover, and a shift toward dominance by juniper mediated by decreased fire frequency (Foster 1917; Buechner 1944; Fuhlendorf et al. 1996). Oaks were the most abundant trees in the Edwards Plateau before 1860 (Weniger 1988), but today juniper dominates the arborescent vegetation of uplands (Van Auken 1988) where not controlled. Increases in juniper populations are a major cause of decreased carrying capacity for livestock in the Edwards Plateau (Smeins et al. 1997). On the other hand, Bryant (1991) suggests that managed juniper woodlands in the region do have potential benefits to wildlife.

Anecdotal reports compiled by Hahn (1951) indicate that when the first domestic cattle were brought to the present site of Kerr Wildlife Management Area (WMA) in 1897, the locality was predominately open grassland with widely scattered scrubby oaks. Juniper stands ranging in size from 2-16 ha existed only in canyons. The area was fenced in 1902. By 1925, the tall bunch grasses had been greatly reduced due to continuous heavy grazing pressure. From 1939-1945, approximately 810 ha of juniper were cleared by hand. Bulldozing and chaining of 84 ha in two pastures occurred in 1947. In 1947-1948, 30 men cut juniper posts for nine months in five pastures. An additional 93 ha of juniper and oak were chained in 1950.

The purpose of this paper is to characterize the historic vegetation structure and tree species composition of a site in the Balcones Canyonlands subregion of the Edwards Plateau, using witness tree data from original land surveys.

STUDY AREA

Kerr Wildlife Management Area is located 13 road miles (21 km) west of Hunt, Kerr County, Texas (30°05'N, 99°30'W). Part of the southern boundary of the WMA is formed by the North Fork

of the Guadalupe River, whose source springs lie along the edge of the property. This 2627.7 ha site was acquired by the Texas Parks & Wildlife Department in 1950 (Hodge 2000). Elevations on Kerr WMA range from 585-679 m. Average annual precipitation at the site is 65 cm.

Much of the vegetation occupying the area has been manipulated to meet deer, range, and endangered species management objectives. Cool season prescribed fire is applied every five years to areas being maintained as savanna or open woodland. A variety of vegetation types are present, including immature, patchy oaks suitable as habitat for the black-capped vireo (*Vireo atricapillus*) and mixed juniper/deciduous woodland favorable to the golden-cheeked warbler (*Dendroica chrysoparia*). Common trees include Ashe juniper (*Juniperus ashei*), Plateau oak (*Quercus fusiformis*), scalybark oak (*Quercus sinuata*), and Texas oak (*Quercus buckleyi*). Post oak (*Quercus stellata*), blackjack oak (*Quercus marilandica*), Lacey oak (*Quercus laceyi*), netleaf hackberry (*Celtis reticulata*), and honey mesquite (*Prosopis glandulosa*) are also present. Prominent grasses include Texas wintergrass (*Nassella leucotricha*), little bluestem (*Schizachyrium scoparium*), common curlymesquite (*Hilaria belangeri*), and sideoats grama (*Bouteloua curtipendula*).

Plateau oak savanna on Kerr WMA from which most Ashe juniper has been cleared has a total tree (>1.5 m) canopy coverage of 25.40%. In decreasing order, Plateau oak, Ashe juniper, and scalybark oak are the most prominent tree species on nine savanna transects. Unmanipulated Ashe juniper forest on one transect in the Spring Pasture has a canopy cover (>1.5 m) of 85.94% Ashe juniper. In decreasing order, the other tree species present there are scalybark oak, Texas oak, Plateau oak, and Lacey oak (Kerr WMA 2003).

Range sites are a concept used by the USDA Natural Resources Conservation Service (NRCS; formerly Soil Conservation Service) to describe the potential vegetation of landscape types. Kerr WMA

uplands encompass primarily Low Stony Hills (43.2%), Steep Rocky (33.4%), and Redland (18.7%) range sites. Smaller areas of Clay Loam (4.2%) and Deep Redland (0.1%) range sites occur along the Bear Creek drainage in the northern portion of the WMA. The Loamy Bottomland site (0.4%) exists along the Guadalupe River. Small areas of Shallow range site can be found outside the WMA boundary. Of the three principal range sites, Redland tends to be found at the highest elevations, Low Stony Hills mostly occupies middle elevations, and Steep Rocky exists primarily on the lowest, most dissected parts of the landscape.

The Low Stony Hills (Comfort, Eckrant, and Tarrant soils) site potential is open grassland with scattered oak mottes (small stands of trees). The Steep Rocky (Eckrant soil) site potential is Plateau oak/Texas oak savanna. The Redland (Spires, Tarpley, and Rough-creek soils) site potential is post oak/Plateau oak savanna. The Clay Loam (Denton soil) site potential is grassland with some Plateau oak, elm, and other woody plants. The Deep Redland (Depalt soil) site potential is post oak savanna. The Shallow (Doss soil) site potential is open grassland with scattered oak mottes (Dittemore & Coburn 1986). The Loamy Bottomland site (Orif and Boerne soils) supports riparian vegetation, dominated along the river's edge by sycamore (*Platanus occidentalis*) and little walnut (*Juglans microcarpa*). Bald cypress (*Taxodium distichum*) does not occur on Kerr WMA, but is present ca. 1 mile (1.6 km) downstream. The riparian vegetation of Kerr WMA most closely resembles that of the upper Sabinal River (see Wood & Wood 1988 and Wood & Wood 1989).

Tree diversity and density vary among the three principal range sites of Kerr WMA, based on a 570 m point-quarter transect ($n = 80$ trees/transect) in each site (trees are defined as stems ≥ 7.62 cm at 1.4 m above ground level). Low Stony Hills has three species—Plateau oak (75.00%), netleaf hackberry (13.75%), and scalybark oak (11.25%); its density is 39.6 trees/ha (22.50% of the stems are

<10 cm; 31.25% are >20 cm). Steep Rocky has four species (Lacey oak is also present but was not recorded on the transect)—Ashe juniper (85.00%), scalybark oak (6.25%), Texas oak (5.00%), and Plateau oak (3.75%); its density is 594.9 trees/ha (7.50% of the stems are <10 cm; 47.50% are >20 cm). Redland has five species—post oak (51.25%), Plateau oak (30.00%), blackjack oak (8.75%), scalybark oak (7.50%), and mesquite (2.50%); its density is 75.6 trees/ha (3.75% of the stems are <10 cm; 81.25% are >20 cm).

The Low Stony Hills site examined (South Rock Pasture) was hand cut in 1944 to remove juniper, heavily browsed by goats until 1967, and burned four times since. The Steep Rocky site examined (Spring Pasture) has never been cleared or burned. The Redland site examined (Plot #6) was cleared of juniper by hand prior to 1991 and burned in 1991, 1998, and 2000 (Armstrong pers. comm.).

METHODS

Bourdo (1956), Jones & Patton (1966), and Schafale & Harcombe (1983) have shown the utility of witness tree data in reconstructing historic vegetation patterns. Witness tree data were obtained from field notes of 20 original land surveys conducted during the years 1876-1884. These survey reports are held in the Archives & Records Division, General Land Office of Texas, 1700 N. Congress Avenue, Austin, Texas 78701.

Data collected included survey number, year, tree species, tree diameter, bearing of tree from survey corner, and distance of tree from survey corner. All survey corners were inside, on, or within 2 km of the WMA boundary. Tree species were frequently abbreviated by the surveyors. These abbreviations were interpreted as follows: L.O. = Plateau (live) oak (*Quercus fusiformis*), P.O. = post oak (*Quercus stellata*), S.O. = scalybark (shin) oak (*Quercus sinuata*), and Sp.O. = Texas (Spanish) oak (*Quercus buckleyi*). Other species included “cedar” = Ashe juniper (*Juniperus ashei*),

blackjack [oak] (*Quercus marilandica*), “water oak” (species undetermined), “elm mott” = cedar elm (*Ulmus crassifolia*), and sycamore (*Platanus occidentalis*).

Diameters were recorded in whole inches and distances in fractional varas (1 vara = 0.84667 m) by the surveyors. The Texas General Land Office apparently did not specify how far surveyors should go from a survey corner to record witness (bearing) trees, but the 1881 manual for the U.S. Public Land Survey required bearing trees to be recorded if they were within 300 links (60.35 m) of the corner (McEntyre 1978). Maximum tree distance reported for the study area exceeded this limit, being 87 varas (73.7 m). In this study, varas were converted to feet through division by 0.36 (Reasonover 1946); radius inches were converted to feet and added to the distance values (Bourdo 1956). Most survey corners with reported trees had two witness trees, but a few indicated one or three. Only those with two or three witness trees were used in computing mean tree distance at a corner.

Weniger's (1988) distance criteria were adopted to determine if a given survey corner (point) represented savanna (>21 m), woodland (7-21 m), or forest (<7 m). Corners with no reported trees were scored as open grassland. Of the 67 points, 65 were survey corners, and two represented locations on a survey line. Most surveys having shared corners agreed with respect to presence/absence of trees, tree species, diameters, bearings, and distances at a given corner. In the few cases where any of these data differed, information from the survey having two witness trees was given priority over surveys having one witness tree or none. A secondary criterion, earlier survey year, was used in cases where the previous criterion did not suffice.

Using ArcView 3.3 GIS, a digitized Texas General Land Office Kerr County survey map (Morriss & Giles 1923, as interpreted by the Railroad Commission of Texas) was superimposed on the

NRCS soils map to provide a basis for locating survey corners and their witness trees within ecological site types at Kerr WMA. Soils were grouped into range sites to facilitate identifying potential differences in vegetation patterns among site types.

Trees per acre were calculated according to the following formula: $43560/d^2$ where d is the mean tree distance in feet (Jones & Patton 1966). All values were converted to centimeters, meters, or trees per hectare for presentation in the tables.

Surveys examined.—Kerr County: 1876: 703 (John W. Brown, surveyor); 1878: 1026, 1031, 1032, 1076 (Francis F. Hopp, surveyor); 1879: 1355 (D. C. Nowlin, surveyor); 1435, 1438 (G. G. Alexander, surveyor); 1881: 1475, 1476, 1477, 1478, 1485, 1486 (B. C. Richards, surveyor); 1882: 1549, 1550, 1551, 1552, 1553 (B. C. Richards, surveyor); 1884: 1874 (B. C. Richards, surveyor).

RESULTS

Witness tree data are presented in Table 1. The most abundant tree was Plateau oak, followed by Ashe juniper, post and Texas oaks, scalybark oak and sycamore, and blackjack oak. The eighth species, cedar elm, was reported only as a motte on a survey line. Post oak and Ashe juniper were the largest trees. Trees with the smallest mean diameters were scalybark oak and sycamore. Plateau oak and Texas oak were intermediate in size. Juniper occurred at four survey corners in Low Stony Hills (3) and Steep Rocky (1) range sites. Based on the relationship between diameter of Ashe juniper and age (Kroll 1980), individuals of this species were 45–106 (mean 78) years old. Sixteen of the 20 points with two or more witness trees had only a single species. In the four cases where more than one species occurred at a point, Plateau oak was associated with Ashe juniper once, with blackjack oak once, and with Texas oak once, and post oak was associated with Texas oak once.

Table 1. Witness trees and their diameters (cm) on Kerr Wildlife Management Area and vicinity, 1876-1884.

Species	<i>n</i>	Range	Mean
<i>Juniperus ashei</i>	6	18-41	30
<i>Quercus buckleyi</i>	4	13-25	19
<i>Quercus sinuata</i>	2	10-15	13
<i>Quercus marilandica</i>	1	10	—
<i>Quercus stellata</i>	4	18-41	31
<i>Quercus fusiformis</i>	24	8-36	19
<i>Quercus</i> sp.	1	10	—
<i>Ulmus crassifolia</i> *	—	—	—
<i>Platanus occidentalis</i>	2	8-25	17

*Recorded as a motte.

There was significantly ($Z = -3.48$, $P = 0.0003$) more open land (grassland and savanna) and less wooded land (woodland and forest) on Kerr WMA than might be expected from the data on historic Kerr County vegetation presented by Weniger (1988). Grass-dominated vegetation types (open grassland lacking trees, and savanna with <23 trees/ha) comprised over 79% of the total points (>82% if single tree points are included), with savanna being less than one-fourth as abundant as grassland (Table 2). The trees at three of the 10 savanna points (30%) had nearly equal distances and bearings at a given point, suggesting that motte formation was relatively common. Eight of the 10 savanna points (80%) had only Plateau oak. One savanna point had Plateau oak and Texas oak. Texas oak was the sole species at the remaining savanna point. Thus, Plateau oak and Texas oak were the only trees represented in savanna. Savanna exhibited little more than 20% of the number of trees in woodland, and under 3% of the amount in forest.

Woody vegetation (woodland and forest) dominated just under 15% of the site (Table 2). Woodland and forest (including riparian forest) were equally abundant. Taken together, there was the same

Table 2. Plant communities at survey points on Kerr Wildlife Management Area and vicinity, 1876-1884.

Community	<i>n</i>	Percent	Mean Distance (m) (range)	Mean Distance (m) (grand mean)	Mean Density (trees/ha)
Grassland	43	64.18	—	—	—
Savanna	10	14.93	21.1-73.8	33.7	8.8
Woodland	5	7.46	12.4-18.0	15.2	43.1
Forest	5	7.46	2.6-6.7	5.5	326.0
Other*	4	5.97	—	—	—
Totals	67	100.00	—	—	—

*Includes two single trees, one elm motte, and one thicket.

amount of woodland and forest (10 points) as savanna. Two woodland points had only Plateau oak, one had Plateau oak and Ashe juniper, one had Plateau oak and blackjack oak, and the remaining point had post oak only. Non-riparian forest (four points) was less dense (254.3 trees/ha) than all forest, but its mean tree density was almost six times that of woodland. Two of these forest points had only Ashe juniper, one had scalybark oak only, and one had post and Texas oaks. Riparian forest was represented by a single point and one species (sycamore). Blackjack oak, post oak, scalybark oak, and sycamore were found only in woodland or forest. Points having a single tree, a thicket, or a motte with no distance information made up under 6% of the total.

Grassland, savanna, and woodland were found throughout the study area. However, wooded points tended to be in the southern part of the study area in proximity to the Guadalupe River. All forest was in the vicinity of the river, but only 60% of the woodland occurred in the southern part of the site. In contrast, 80% of savanna points were located in the northern portion of the study site. With reference to the three principal range sites of Kerr WMA, 60-80% of the points in them were grassland (Table 3). There was no

association between ecological site types (range sites) and plant community structure ($\chi^2 = 4.18$, n.s.).

Comparison of past and present vegetation on the three principal range sites at Kerr WMA indicates that open grassland has disappeared since the historic surveys were conducted (Table 3). Its place has been taken by woodland and forest communities. The increase in density is most marked in the Steep Rocky site, specifically that portion not subject to vegetation management (Spring Pasture and Spring Trap).

DISCUSSION

Increases in woody plants on Edwards Plateau uplands due to ranching activities did not become evident prior to 1887-1892 (Foster 1917; Buechner 1944). Barbed wire fences were absent in Kerr County before 1883 (Buechner 1944), and the San Antonio & Aransas Pass Railway, a major shipper of juniper fence posts (Bray 1904), did not reach Kerrville until 1887 (Zlatkovich 1981). The youngest Ashe juniper witness tree on the Kerr WMA site was already established ca. 15 years before the Balcones Canyonlands began to be settled by Europeans. Livestock numbers were still relatively low (<25,000 animal units or 22.17 A.U./section) in Kerr County (Spaight 1882) and domestic stock were largely unconfined. There appear to have been no domestic cattle on the uplands of the Kerr WMA site until 1897 (feral longhorns were present, however), and the area was unfenced prior to 1902 (Hahn 1951). For these reasons, it is doubtful that significant woody vegetation change due to grazing or post cutting had occurred on lands surveyed during the period 1876-1884. The available evidence suggests that vegetation on the Kerr WMA site changed between 1902 and 1925.

Presettlement fire frequency in that portion of the Edwards Plateau including Kerr WMA was every 7-25 years (Frost 1998). Warm season burns at this return interval would have maintained

Table 3. Plant community change in principal range sites of Kerr Wildlife Management Area, 1884-2004.

Plant Community	Low Stony Hills	Low Stony Hills	Steep Rocky	Steep Rocky	Redland	Redland
	1884 <i>n</i> = 35	2004 <i>n</i> = 20	1884 <i>n</i> = 15	2004 <i>n</i> = 20	1884 <i>n</i> = 10	2004 <i>n</i> = 20
Grassland	68.6%	—	80.0%	—	60.0%	—
Savanna	17.1%	15.0%	6.7%	—	20.0%	10.0%
Woodland	5.7%	80.0%	6.7%	5.0%	20.0%	70.0%
Forest	8.6%	5.0%	6.7%	95.0%	—	20.0%

open grassland or savanna conditions (Fuhlendorf et al. 1996), except in sites protected from fire by topographic breaks or rocky outcrops. Fonteyn et al. (1988) reported that open Plateau oak savanna would result from summer burns followed by root sprouting. This mechanism offers a plausible explanation for the historical savanna vegetation on Kerr WMA. They also indicated that areas on Kerr WMA currently having Plateau oak/Ashe juniper mottes surrounded by grassland are a consequence of frequent cool season burns.

Overgrazing near streams after settlement undoubtedly reduced the incidence of grassland fires (Foster 1917), but woodland fires were common during the period 1879-1904 (Bray 1904). As much as 11.5% of the eastern Edwards Plateau may have burned in those 25 years (Foster et al. 1917).

Weniger (1988) concluded, based on pre-1860 witness tree information, that Kerr County’s wooded areas were historically “savanna-like.” No support for that conclusion can be found in his data. The mean tree distance he gives as 22.9 meters is apparently a lapsus for 22.9 feet, which correlates exactly with his calculation of 205 trees/ha in wooded areas. This density indicates forest or

closed woodland, not open woodland or savanna. The mean tree distance of wooded points (woodland and forest) on Kerr WMA during 1876-1884 was 10.35 m, indicating that the tree stands there were considerably more open (93 trees/ha) than the Kerr County average (205 trees/ha) reported by Weniger (1988).

Weniger (1988) found, based on witness tree data from surveys prior to 1860, that Kerr County was 61.0% grassland and savanna, and 39.0% woodland and forest. He attempted to avoid documenting the woody vegetation changes brought about by European settlement by using only the earliest survey data. However, there are inherent biases in using pre-1860 Edwards Plateau surveys exclusively, the most important being that most of them were located along stream valleys (Weniger 1984) where woodland and forest tend to be more common. It is notable that Spaight (1882) reported adjacent Edwards, Bandera, and Kendall counties to be only 20-33% wooded (no data available for Kerr County). Weniger (1988) observed that Kerr County was the least wooded (39.0%) of the Edwards Plateau counties, but his percentages for Bandera (45.8%) and Kendall (47.9%) counties (versus 33% for both in Spaight 1882) suggest overestimation of the fraction of Kerr County that was wooded.

CONCLUSIONS

Forty-three witness trees (plus one motte) of eight identifiable species were observed in the historic landscape. Plateau oak and Ashe juniper were the most common trees, with Plateau oak being four times as abundant as Ashe juniper. Other oaks observed included blackjack, post, scalybark, and Texas. Cedar elm (in a motte) and sycamore (in riparian forest) were the only other species noted. The largest mean diameters were attained by post oak and Ashe juniper.

Kerr WMA was dominated by open grassland (ca. 64% of the site) during the period 1876-1884, as documented by witness tree

data from original land surveys. Wooded areas (woodland and forest) comprised only about 15% of the site. Savanna was also found on about 15% of the site. Motte formation was relatively common in savanna, though not the most frequent condition. Mean tree density in savanna was almost 9/ha, compared with 43/ha in woodland and 326/ha in forest. Grassland, savanna, and woodland were widely distributed on the Kerr WMA site, but 80% of wooded points (including all forest) lay in the southern portion nearer the Guadalupe River and 80% of savanna points occurred in the northern part of the area farther from the river. However, no apparent association existed between ecological site types (range sites) and the historic vegetation structure of Kerr WMA.

Vegetation change in the Edwards Plateau involving trees (other than baldcypress harvested prior to 1875 [Weniger 1984]) evidently occurred somewhat later than is often assumed. These changes, in upland sites particularly, became noticeable no earlier than the late 1880s, and probably began a decade or more later on Kerr WMA (1897-1902). Although Kerr WMA is managed in a fashion that attempts to mimic historic ecological processes (fire, grazing), it is not precisely analogous to the 19th century landscape in terms of its current vegetative structure. The 1876-1884 landscape was apparently much more open than the contemporary one. Grassland is no longer dominant, and has been replaced by communities having woodland and forest densities. Warm season burns formerly reduced the density and height of woody plants, in particular those capable of reaching tree size. Cool season burns employed by land managers at Kerr WMA are not as effective in suppressing woody vegetation.

Wooded areas in Kerr County as a whole surveyed before 1860 apparently did not resemble savanna, at least in terms of the definition provided by Weniger (1988) and adopted in this paper. Furthermore, woodland and forest at that time were likely a smaller

proportion of the county than Weniger's witness tree study indicated, due to bias in his sampling scheme toward valley areas.

The site of Kerr WMA may not be a good historical analog for the Balcones Canyonlands as a whole, as it lies at the upper extreme of the Guadalupe watershed. Due to its location, much of the study area is relatively undissected upland. More data from larger geographic areas are needed to better characterize historic Edwards Plateau vegetation.

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A SYSTEMATIC CHECKLIST OF THE LAND SNAILS OF LOUISIANA

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Abstract.—Reviews of literature and museum records indicate that 141 species of land snail occur in Louisiana. This represents an increase of 39 species from the most recently published works. Diversity by parish is presented, along with a discussion of record paucity for certain parishes and future survey plans.

Resumen.—Repasos de la información publicada y de los archivos del museo muestra que se encuentran ciento cuarenta y una (141) especies de los caracoles terrestres en Louisiana. Esta información indica un aumento de treinta y nueve (39) especies más de las reportadas en las publicaciones más recientes. La diversidad entre los condados se presenta con una discusión de la falta de la información en los archivos en ciertos condados y de planes futuros.

Checklists of land snail faunas are common at local, state, and regional levels (e.g., Tryon 1866; Sterki 1907; Walker 1928; Baker 1939; Archer 1941; Hubricht 1973; 1985). These lists serve as important baseline inventories of biodiversity for the areas surveyed. Data can then be used for the identification of diversity hotspots, tracking of introduced taxa, and conservation and management efforts (Lydeard et al. 2004). Historical information can be gathered from the literature to some extent, but more information exists in museum and other natural history collections (Mikkelsen & Bieler 2000; Ponder et al. 2001), especially when collection efforts accurately reflect diversity at increasing regional levels (Bouchet et al. 2002).

The land snails of Louisiana remain an understudied fauna in North America. Few efforts to catalog the native land snail diversity of the state exist, though some authors did provide detailed accounts of collections (e.g., Frierson 1899; Harry 1942). Much more attention has been paid to the state's non-indigenous species, especially given the importance of New Orleans as an international

commerce port (e.g., Harry 1948; 1951; Dundee 1970; 1974). Dundee & Watt (1961) provided a preliminary checklist of Louisiana land snails comprising records of 73 nominal taxa from literature sources, including those given in Pilsbry (1939; 1941), while Hubricht (1985) listed 102 species. Natureserve Explorer (Natureserve 2004), an on-line biodiversity database, lists only six species in Louisiana. In order to gain a more accurate and complete understanding of Louisiana's terrestrial mollusk diversity, parish (= county) records from a variety of museum and literature sources were examined to produce a list of the state's land snails.

METHODS

Occurrence records were taken from a variety of literature sources (Frierson 1899; Taylor 1899; Smith 1912; Vanatta 1912; Viosca 1928; Pilsbry 1939; Goodrich 1940; Pilsbry 1941; Harry 1942; Haas 1945; Harry 1948; 1951; Hubricht 1956; Branson 1961; Dundee & Watt 1961, 1962; Hubricht 1963; Herman & Dundee 1964; Herman et al. 1965; Dundee 1970; 1974; Hubricht 1985). Collection records were examined from the following museums: Academy of Natural Sciences, Philadelphia; Field Museum of Natural History, Chicago; Florida Museum of Natural History, Gainesville; and Carnegie Museum of Natural History, Pittsburgh. The Academy and Field Museum cover the majority of collections made by Pilsbry and Hubricht respectively. Only records with data down to parish level were used for parish counts. While this potentially excluded taxa, it increased the accuracy of occurrence. Invasive species (Burch 1962; Robinson 1999) were included, though intercepted alien species (Dundee 1974) not established were not. Taxonomy and nomenclature generally follow Turgeon et al. (1998) or more recent published sources.

RESULTS

Museum collections and literature sources recorded the presence of 141 species of land snails in Louisiana, comprising 22 families in four orders (Table 1). Stylommatophora was the most

Table 1. Systematic list of land snails recorded in Louisiana. Values in parentheses represent the number of families and species in each order. Taxa marked with an asterisk (*) are considered alien species (Burch 1962; Robinson 1999). Specific by-parish records are available from the authors.

Order Basommatophora (1, 3)
Family Carychiidae
<i>Carychium exiguum</i> (Say 1822)
<i>Carychium exile</i> Lea 1842
<i>Carychium mexicanum</i> Pilsbry 1891
Order Neritopsina (1, 1)
Family Helicinidae
<i>Oligyra orbiculata</i> Say 1818
Order Stylommatophora (19, 135)
Family Bradybaenidae
* <i>Bradybaena similaris</i> (Ferrusac 1821)
Family Bulimulidae
<i>Rabdotus dealbatus</i> (Say 1830)
Family Cerionidae
<i>Cerion incanum</i> (Binney 1851)
Family Discidae
<i>Anguispira alternata</i> (Say 1816)
<i>Anguispira strongyloides</i> (Pfeiffer 1854)
<i>Discus patulus</i> (Deshayes 1830)
Family Haplotrematidae
<i>Haplotrema concavum</i> (Say 1821)
Family Helicarionidae
* <i>Dryachloa dauca</i> Thompson & Lee 1981
<i>Euconulus chersinus</i> (Say 1821)
<i>Euconulus dentatus</i> (Sterki 1893)
<i>Euconulus trochulus</i> (Reinhardt 1883)
<i>Guppya sterkii</i> (Dall 1888)
Family Helicidae
* <i>Cornu aspersum</i> (Müller 1774)
* <i>Cornu aperta</i> (Born 1778)
* <i>Eobania vermiculata</i> (Müller 1774)
* <i>Otala lactea</i> (Müller 1774)
Family Helicodiscidae
<i>Helicodiscus inermis</i> Baker 1929
<i>Helicodiscus notius</i> Hubricht 1962
<i>Helicodiscus paralellus</i> (Say 1817)
<i>Helicodiscus singleyanus</i> (Pilsbry 1889)
Family Limacidae
<i>Deroceras laeve</i> (Müller 1774)
* <i>Limax flavus</i> Linnaeus 1758
* <i>Limax marginatus</i> Müller 1774
Family Philomycidae
<i>Megapallifera mutabilis</i> (Hubricht 1951)

Table 1. Cont.

-
- Pallifera marmorea* Pilsbry 1948
Philomycus carolinianus (Bosc 1802)
Philomycus togatus (Gould 1841)
- Family Polygyridae
- Allogona profunda* (Say 1821)
Daedalochila auriculata (Say 1818)
Daedalochila auriformis (Bland 1859)
Daedalochila leporina (Gould 1848)
Daedalochila postelliana (Bland 1859)
Daedalochila triodontoides (Bland 1861)
Euchemotrema fraternum (Say 1824)
Euchemotrema leai (Binney 1841)
Inflectarius inflectus (Say 1821)
Linisa texasiana (Moricand 1833)
Mesodon clausus (Say 1821)
Mesodon elevatus (Say 1821)
Mesodon sanus (Clench & Archer 1933)
Mesodon thyroidus (Say 1816)
Mesodon zaletus (Binney 1837)
Millerelix dorfeuilliana (Lea 1838)
Neohelix albolabris (Say 1816)
Neohelix alleni (Sampson 1883)
Neohelix divesta (Gould 1848)
Patera appressa (Say 1821)
Patera perigrapta (Pilsbry 1894)
 **Praticolella griseola* (Pfeiffer 1841)
Polygyra cereolus (Muhlfeld 1816)
Polygyra septemvolva Say 1818
Stenotrema barbatum (Clapp 1904)
Stenotrema stenotrema (Pfeiffer 1842)
Stenotrema labrosum (Bland 1862)
Triodopsis cragini Call 1886
Triodopsis hopetonensis (Shuttleworth 1852)
Triodopsis vultuosa (Gould 1848)
Xolotrema caroliniense (Lea 1834)
Xolotrema fosteri (Baker 1921)
Xolotrema obstrictum (Say 1821)
- Family Punctidae
- Punctum minutissimum* (Lea 1841)
Punctum vitreum (Baker 1930)
- Family Pupillidae
- Gastrocopta abbreviata* (Sterki 1909)
Gastrocopta armifera (Say 1821)
Gastrocopta contracta (Say 1822)
Gastrocopta corticaria (Say 1816)
Gastrocopta cristata (Pilsbry & Vanatta 1900)

Table 1. Cont.

<i>Gastrocopta pellucida</i> (Pfeiffer 1841)
<i>Gastrocopta pentodon</i> (Say 1822)
<i>Gastrocopta procera</i> (Gould 1840)
<i>Gastrocopta riparia</i> Pilsbry 1916
<i>Gastrocopta rupicola</i> (Say 1821)
<i>Gastrocopta tappaniana</i> (Adams 1842)
* <i>Pupisoma dioscoricola</i> (Adams 1845)
<i>Pupisoma macneilli</i> (Clapp 1918)
<i>Pupoides albilabris</i> (Adams 1841)
<i>Pupoides modicus</i> (Gould 1848)
<i>Vertigo gouldi</i> (Binney 1843)
<i>Vertigo milium</i> (Gould 1840)
<i>Vertigo oralis</i> Sterki 1898
<i>Vertigo oscariana</i> Sterki 1890
<i>Vertigo ovata</i> Say 1822
<i>Vertigo rugosula</i> Sterki 1890
<i>Vertigo teskeyae</i> Hubricht 1961
<i>Vertigo tridentata</i> Wolf 1870
Family Spiraxidae
<i>Euglandina rosea</i> (Ferussac 1818)
Family Streptaxidae
* <i>Huttonella bicolor</i> (Hutton 1834)
Family Strobilopsidae
<i>Strobilops aeneus</i> Pilsbry 1926
<i>Strobilops labyrinthicus</i> (Say 1817)
<i>Strobilops texasianus</i> Pilsbry & Ferriss 1906
Family Subulinidae
* <i>Allopeas gracile</i> (Hutton 1834)
* <i>Lamellaxis mauritanus</i> Pfeiffer 1852
* <i>Opeas pumilum</i> (Pfeiffer 1840)
* <i>Opeas pyrgula</i> Schmacker & Boettger 1891
* <i>Rumina decollata</i> (Linnaeus 1758)
Family Succineidae
<i>Catinella oklahomarum</i> (Webb 1953)
<i>Catinella texana</i> Hubricht 1961
<i>Catinella vermeta</i> (Say 1829)
<i>Novisuccinea ovalis</i> (Say 1817)
<i>Oxyloma salleanum</i> (Pfeiffer 1849)
<i>Succinea campestris</i> Say 1817
<i>Succinea forsheyi</i> Lea 1864
<i>Succinea greerii</i> Tryon 1866
<i>Succinea grosvenori</i> Lea 1864
<i>Succinea luteola</i> Gould 1848
<i>Succinea unicolor</i> Tryon 1866
Family Zonitidae
<i>Glyphyalinia indentata</i> (Say 1823)

Table 1. Cont.

<i>Glyphyalinia lewisiana</i> (Clapp 1908)
<i>Glyphyalinia luticola</i> Hubricht 1966
<i>Glyphyalinia praecox</i> (Baker 1930)
<i>Glyphyalinia roemeri</i> (Pilsbry & Ferriss 1906)
<i>Glyphyalinia sculptilis</i> (Bland 1858)
<i>Glyphyalinia solida</i> (Baker 1930)
<i>Glyphyalinia umbilicata</i> (Cockerell 1893)
<i>Glyphyalinia wheatleyi</i> (Bland 1883)
<i>Hawaiiia alachuana</i> (Dall 1885)
<i>Hawaiiia minuscula</i> (Binney 1841)
<i>Mesomphix capnodes</i> (Binney 1857)
<i>Mesomphix friabilis</i> (Binney 1857)
<i>Mesomphix globosus</i> (MacMillan 1940)
<i>Mesomphix vulgatus</i> Baker 1933
<i>Nesovitrea electrina</i> (Gould 1841)
<i>Paravitrea conecuhensis</i> (Clapp 1917)
<i>Paravitrea multidentata</i> (Binney 1840)
<i>Paravitrea significans</i> (Bland 1866)
<i>Striatura exigua</i> (Stimpson 1850)
<i>Striatura meridionalis</i> (Pilsbry & Ferriss 1906)
<i>Striatura milium</i> (Morse 1859)
<i>Ventridens demissus</i> (Binney 1843)
<i>Ventridens gularis</i> (Say 1822)
<i>Ventridens intertextus</i> (Binney 1843)
<i>Ventridens ligera</i> (Say 1821)
<i>Ventridens pilsbryi</i> Hubricht 1964
<i>Zonitoides arboreus</i> (Say 1816)
<i>Zonitoides nitidus</i> (Müller 1774)
Order Systellommatophora (1, 2)
Family Veronicellidae
* <i>Angustipes ameghini</i> (Gambetta 1923)
<i>Leidyula floridana</i> (Leidy 1851)

represented order, with 19 families and 135 species. Polygyridae was the most represented family with 33 species. Based on records with given parish localities, East Baton Rouge Parish had the highest diversity with 59 species, followed by West Feliciana Parish with 57 (Table 2). Avoyelles, Beauregard, Bossier, St. James, and Webster parishes lacked any specific records for land snail presence. Mean diversity was approximately 14 species per parish (Fig. 1). *Zonitoides arboreus* (Say 1816) was the most

Table 2. Number of land snail species recorded by parish.

Parish	No. Species	Parish	No. Species
Acadia	5	Madison	16
Allen	8	Morehouse	16
Ascension	14	Natchitoches	8
Assumption	5	Orleans	46
Avoyelles	0	Quachita	13
Beauregard	0	Plaquemines	16
Bienville	10	Pointe Coupee	15
Bossier	0	Rapides	41
Caddo	32	Red River	1
Calcasieu	20	Richland	12
Caldwell	5	Sabine	1
Cameron	8	St. Bernard	23
Catahoula	16	St. Helena	2
Claiborne	8	St. James	0
Concordia	19	St. John the Baptist	15
De Soto	29	St. Landry	18
East Baton Rouge	59	St. Martin	10
East Carroll	11	St. Mary	17
East Feliciana	11	St. Tammany	31
Evangeline	11	Tangipahoa	11
Franklin	11	Tensas	16
Grant	16	Terrebonne	18
Iberia	8	Union	2
Iberville	6	Vermillion	5
Jackson	2	Vernon	9
Jefferson	47	Washington	6
Jefferson Davis	4	Webster	0
Lafayette	7	West Baton Rouge	27
Lafourche	9	West Carroll	3
La Salle	17	West Feliciana	57
Lincoln	9	Winn	5
Livingston	17		

widespread species, with records in 40 parishes. Forty-nine (35%) of the species were either recorded in a single parish, or presumed to occur in the state with no specific parish record (Hubricht 1985). Seventeen alien species (12%) were recorded, mostly from Orleans Parish. Mean recorded occurrence was over six parishes per species. No records for any federally listed proposed, candidate,

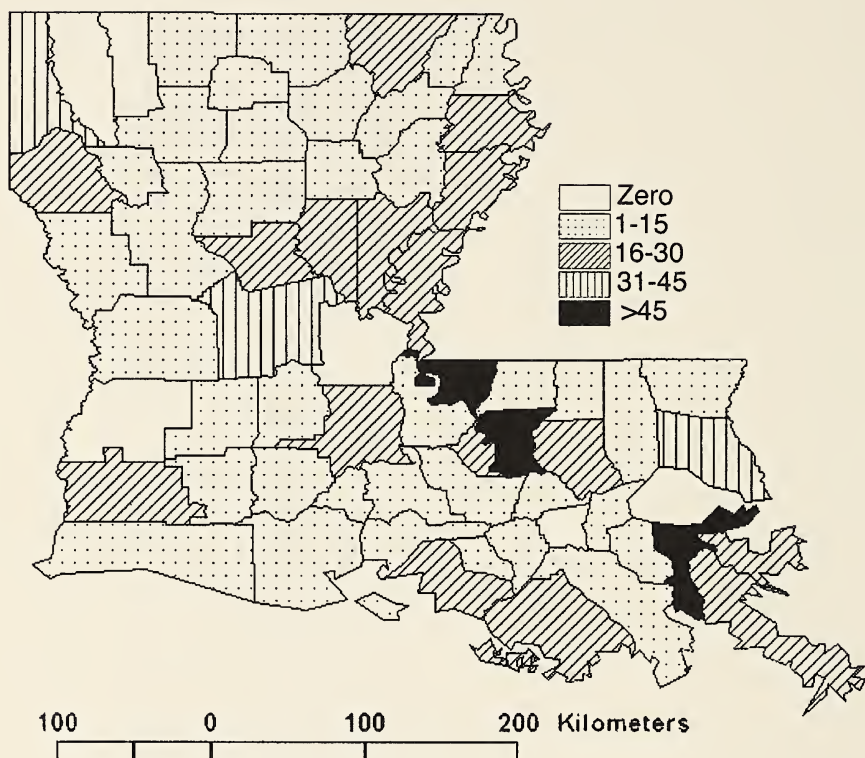


Figure 1. Map of Louisiana parishes indicating the number of species recorded in each.

threatened, or endangered species (USFWS, 2004) were found for Louisiana.

DISCUSSION

The land snail fauna of Louisiana represents a poorly understood and understudied group of taxa. While the state's vertebrate faunas have been treated (Lowery 1974; Dundee & Rossman 1989; Douglas 1993; Alsop 1998), very little is known concerning the terrestrial mollusks even at the basic taxonomic and identification levels. The recorded diversity of land snails in the state is lower than that of nearby states like Texas (195 sp.; Perez 2004) and

Alabama (194 sp.; Shelton 1998). This study increased the number of recorded species by 38% from Hubricht's (1985) study and by 93% from that of Dundee & Watt (1961). The lack of records for five parishes and the overall disparity in records highlights the need for increased surveying statewide. The parishes with the highest recorded diversity are those containing or adjacent to Louisiana's largest cities, such as East Baton Rouge (contains Baton Rouge). This trend is common especially in museum collections, and frequently leads to distributions and diversity assessments that are both incorrect and unsupported (Hijmans et al. 2000; Williams et al. 2002). Consistent, rigorous sampling of the state's malacofauna should help reverse this trend.

The general importance of faunal lists and surveys is exemplified by the overall decline of non-marine mollusk species worldwide. Sadly, 42% of the 693 recorded animal extinctions since the year 1500 were mollusks, and 99% of these were non-marine. Also, much has been written arguing that scientists and management agencies can conserve biological diversity only when they know what they are conserving. In contrast to the better-known vertebrate groups, less than 2% of the estimated 31,000 named mollusk species have had their conservation status properly assessed. Add to this the 11,000 to 40,000 terrestrial species still undescribed (Lydeard et al. 2004), and the plight of the world's mollusks becomes clear. Lists such as the one presented here provide the foundation for further studies, including those involving phylogenetic and phylogeographic methods (Lydeard & Lindberg 2003) to more completely understand the biodiversity of a given area.

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THE EFFECT OF ENCOUNTER EXPERIENCE
ON HUNTING BEHAVIOR IN THE SPIDER WASP,
PEPSIS CERBERUS LUCAS (HYMENOPTERA: POMPILIDAE)

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Abstract.—Laboratory experiments were conducted to assess the effects of encounter experience with a host on the hunting behavior of naive females of the spider wasp, *Pepsis cerberus* (Hymenoptera: Pompilidae). The time required to complete the overall hunting sequence decreased significantly from a mean of 189.4 min for the first encounter with a host spider, *Aphonopelma steindachneri*, to 153.1 min after the eighth encounter. The performance of certain behavioral components of hunting improved with experience (initial approach to the host, and antennation / paralyzation) whereas others did not (grooming of antennae, burial and oviposition, and closure of the nest entrance). Results show that certain components of otherwise inflexible instinctive behaviors can be modified by experience.

The hunting behavior of tarantula hawk wasps of the genus *Pepsis* (Hymenoptera: Pompilidae) has been a topic of interest in both the popular and scientific literature since the early descriptions of Petrunkevitch (1926) and Passmore (1936). *Pepsis* wasps are one the most conspicuous representatives of the arthropod fauna of North American deserts (Hurd 1952; Punzo 1994a). Pompilid wasps are characterized by the following behavioral traits (Evans & Eberhard 1970): (1) utilization of spiders as a food source (host) for larvae; (2) each wasp larva is provided with a single paralyzed host; (3) paralyzed hosts are dragged backwards by the female wasp over the ground surface and placed in the nest (burrow) where a single egg is deposited on the abdomen of the spider; (4) the abdomen of the wasp is used to compress the soil in the closure of the nest entrance. Although adult male and female *Pepsis* wasps are nectivorous, (Field 1992), the females selectively hunt large theraphosid (tarantula) spiders as hosts for their developing larvae (Williams 1956; Punzo 1990).

In the earlier literature the hunting behavior of *Pepsis* wasps has often been cited as a classical example of a stereotypical instinctive

(innate) behavior comprised of an inflexible sequence of behavioral acts (Lucas 1919; Petrunkevitch 1926; Cazier & Mortenson 1964) referred to as fixed action patterns (FAPs) (Tinbergen 1951). In contrast, more recent analyses have shown that experience can modify certain components of innate behavioral acts in response to local environmental demands (Punzo 1996; 2000), giving rise to the concept of modal action patterns (MAPs, Barlow 1968).

Some degree of plasticity in hunting behavior has been observed for some species of *Pepsis* wasps. For example, females of *P. formosa* may or may not rub the lateral area of their abdomens with the mesothoracic legs during encounters with host spiders (Punzo & Garman 1989). In addition, following paralyzation of the host, females frequently (but not always) exhibit lapping behavior whereby they drink hemolymph oozing from the site where the stinger was inserted (wound site) or liquid material from the mouth of the host. Thus, there is flexibility in the sense that lapping behavior may or may not be exhibited, and if it does occur, the site where it is initiated may vary. There is some evidence that the occurrence of lapping behavior is influenced by the amount of time the female wasp spent in flight searching for a suitable host (Punzo 2000).

The hunting behavior for a few species of *Pepsis* wasps has been described in detail, including *Pepsis marginata* (Petrunkevitch 1926; 1952), *Pepsis thisbe* (Williams 1956; Punzo 1994b), and *P. formosa* (Punzo & Garman 1989). To summarize, female wasps fly over variable distances and appear to visually locate spiders wandering over the ground surface. In other cases, females will alight on the ground using rapid walking movements to locate occupied spider burrows. If a spider has been encountered on the surface, the wasp taps the spider's body with her antennae, a behavior known as antennation, presumably utilizing olfactory cues to assess the suitability of the host. If suitable (correct species), the wasp then moves away from the host and passes the antennae through her mandibles, a behavioral component known as grooming. After a variable period of time, the wasp returns to the spider, resumes

antennation, and then rushes under the host and uses her mandibles to seize one of the spider's posterior legs. Once this occurs, the spider is usually flipped on its back and the wasp searches for a suitable site to insert the stinger. Following insertion of the stinger and evenomation, the spider exhibits rapid paralysis and a curling of its legs over its abdomen. The wasp then moves away from the paralyzed host, resumes grooming, and may or may not exhibit lapping behavior.

If the spider is within its burrow, the wasp enters and forces the spider onto the ground surface before continuing the sequence of behavioral acts described above. Because there are no reports of a *Pepsis* female attacking and stinging a tarantula within its burrow (Punzo 2000), it has been suggested that the confines of the burrow may not provide adequate space for the maneuverability required to grasp the spider and insert the stinger (Baerg 1958; Petrunkevitch 1952; Punzo & Garman 1989).

Following paralyzation, the wasp will excavate her own burrow (nest) if a spider burrow is not available; otherwise, she will utilize the spider's burrow as her nest. The spider is dragged into the burrow and a single egg is deposited on its abdomen. The wasp then uses her legs to cover the burrow entrance and her abdomen to compress the soil. Thus, the hunting sequence of *Pepsis* wasps can be divided into the following behavioral components (acts): (1) initial approach and antennation (APA), moving away and grooming (MG), antennation and paralyzation (ANP), burial and oviposition (BO), and closure of the nest (CL) (Evans & Eberhard 1970; Punzo 1991).

This study attempts to determine what effects previous encounter experience with the host may have on the hunting behavior of *Pepsis cerberus*, with particular emphasis on the amount of time required to complete the overall hunting sequence and the individual behavioral components of hunting.

MATERIALS AND METHODS

Host spiders, as well as eggs and developing larvae of *P. cerberus*, were collected from burrows of parasitized spiders (*Aphonopelma steindachneri*) located in Big Bend National Park (Brewster County, Texas, USA), during spring and summer of 2003, and transported to the laboratory. This park lies within the northern region of the Chihuahuan Desert. To ensure genetic diversity among wasps used in these experiments, parasitized spiders were collected from burrows separated by a minimum distance of 7.5 km, a distance in excess of the home ranges reported for these wasps (Punzo 2000).

Following pupation, emergent adult male and female wasps were housed separately in 1-L glass cylindrical containers and maintained at $22 \pm 0.5^{\circ}\text{C}$, 65 - 70% relative humidity. They were fed on a diet consisting of honey and a 2% glucose solution. Thus, all female wasps used in these experiments (15 to 18 days of age; mean body weight: $3.06 \text{ g} \pm 0.09 \text{ SE}$) were naive (had no previous encounter experience with the host spider). In addition, all spiders were adult females (mean body weight: $8.25 \text{ g} \pm 0.14 \text{ SE}$) that had been obtained from egg sacs deposited by spiders in captivity, and had no previous experience with wasps.

Ten encounters with a host spider were staged in a test chamber for each of 10 female wasps. A different female tarantula was used for each encounter, and a 24-hr intertrial interval was used between individual encounters. The test chamber was constructed of clear plexiglass, and was 50 cm (length) by 40 cm (width) by 40 cm (height). The floor was covered to a depth of 15 cm with a substrate consisting of a mixture of sand and adobe soil originally obtained from spider collection sites in the field. This depth was sufficient to allow the wasp to excavate a burrow (nest). The top of the chamber contained a hole (3 cm in diam) located at its center that was used to introduce for encounter trials. All observations were made through a one-way mirror to minimize disturbance to

the animals, and were recorded using a Panasonic 815D video recorder.

Before the initiation of encounter trials, all of the wasps used in these experiments were allowed to explore the test chamber for 2 hr a day for five days in order to allow wasps to become familiar with the confines of the chamber. Preliminary observations showed that this significantly reduced the amount of time and energy used by wasps in trying to escape. Before each trial, a female spider was removed from its cage and placed in an inverted plastic container for transport to the test chamber. To initiate a trial, the spider was placed at the center of the chamber floor, and the plastic container removed. Following a 5-min period, a female wasp was introduced into the chamber using the hole located at its top. The time required for the completion of the following behavioral components of the hunting sequence was recorded: APP (initial; approach and antennation); MG (moving away and grooming); ANP (antennation and paralyzation); BO (burial and oviposition); and CL (closure of the nest entrance). Following data collection, wasp and paralyzed spiders were preserved in 80% ethanol and placed in the Invertebrate Collection at the University of Tampa.

All statistics used in data analysis followed procedures as outlined by Sokal & Rohlf (1955). To analyze the effects of encounter experience on the time required to complete the behavioral components of hunting an analysis of variance (*ANOVA*) was used since a Bartlett's Test showed homogeneity of variances and G-Tests indicated that error variances were normally distributed. Scheffe F tests were used to determine significance between various means for individual behavioral components.

RESULTS AND DISCUSSION

Results show that the amount of time required by female wasps to complete the overall hunting sequence decreased as a function of the number of encounters with a host spider (Fig. 1), from a mean of 189.4 min during the first encounter, to 153.1 min for the tenth

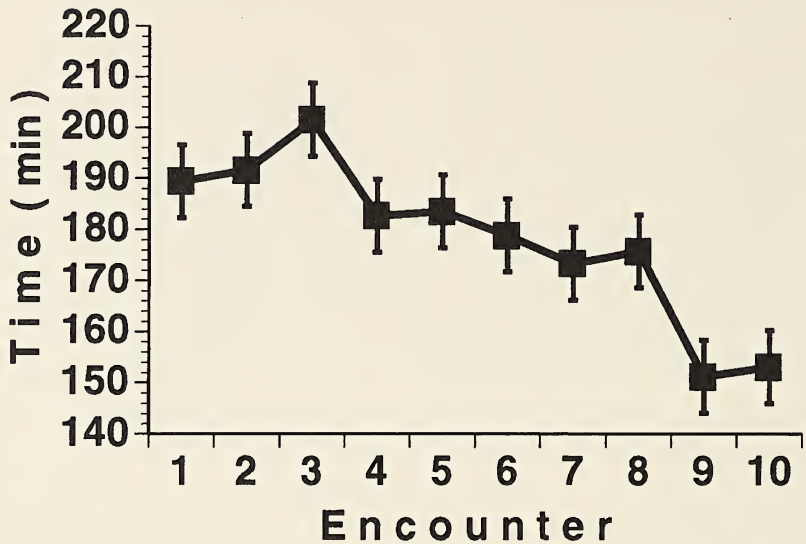


Figure 1. Time (in min) required for females of the spider wasp *Pepsis cerberus* to complete all behavioral components of the hunting sequence as a function of the number of encounters with a host spider. Data express as means for 10 wasps. Vertical bars represent $\pm SE$. Significantly less time was required to perform the overall hunting sequence for encounters 9 and 10 ($P < 0.05$) as compared to that required for encounters 1 to 8.

encounter ($F = 27.21$, $df = 9,45$, $P < 0.01$). This reduction in time was significant after eight encounters. This improvement in performance can be considered a change in behavior (behavioral plasticity) that resulted from experience, thereby satisfying a common definition for learning (Bitterman 1975). A similar effect of experience on enhanced efficacy of hunting in pepsine wasps has been reported for *P. formosa* (cf. Punzo & Garman 1989; Punzo 1991) and *P. thisbe* (Punzo 1994b). In terms of energy budgets (cost-benefit analysis), additional time spent in acquiring needed resources is rendered unavailable for other activities such as mating and reproduction. In addition, the more time an animal spends engaged in foraging activities, the more it will be exposed to potential predators. Thus, the ability to reduce the amount of time allocated toward search, pursuit, capture, and handling of prey

Table 1. The effect of encounter experience on the time (min) required for females of *Pepsis cerberus* to complete various behavioral components of the overall hunting sequence. Data expressed as means ($\pm$ SE) for 10 wasps, APP (approach and antennation); MG (moving away and grooming); ANP (antennation and paralyzation); BO (burial and oviposition); CL (closure of the nest entrance). Values in columns followed by different letters are significantly different ($P < 0.01$).

Encounter No.	Behavioral Components				
	APP	MG	ANP	BO	CL
1	27.8a (3.7)	8.5 (1.2)	7.1a (0.7)	25.7 (4.9)	108.8 (12.4)
2	31.4a (4.2)	11.3 (2.5)	6.6a (0.4)	29.4 (5.2)	116.3 (9.9)
3	23.5a (4.7)	9.5 (1.9)	7.7a (0.6)	34.5 (6.7)	124.3 (13.1)
4	21.4a (3.6)	13.4 (3.2)	5.7a (0.5)	26.7 (3.7)	104.2 (7.8)
5	10.3b (1.6)	10.6 (2.1)	6.6a (0.7)	31.2 (5.5)	97.5 (6.5)
6	12.3b (2.4)	8.8 (1.1)	4.3b (0.5)	28.8 (3.4)	119.5 (10.2)
7	10.2b (1.1)	12.2 (2.5)	3.4b (0.6)	32.5 (5.7)	106.6 (11.2)
8	6.5c (0.4)	9.8 (1.8)	3.1b (0.4)	33.4 (4.1)	114.7 (9.9)
9	7.2c (0.6)	10.5 (0.8)	2.6b (0.3)	27.8 (3.8)	99.7 (8.9)
10	6.7c (0.3)	9.3 (0.6)	2.8b (0.2)	30.4 (4.1)	118.9 (10.6)

should increase the overall fitness of predators (Krebs 1978; Punzo 2002). In this respect, selection should favor the evolution of adaptive behavioral programs that allow for a certain degree of plasticity (Punzo 1996).

With respect to specific behavioral acts, there was a significant reduction in the amount of time required to complete APP and ANP components ($F = 32.67$, $P < 0.01$). In contrast, female wasps showed no improvement in performance for the MG, BO and CL components (Table 1). Thus, APP and ANP exhibit a degree of plasticity as a result of experience, whereas MG, BO and CL are not similarly affected. It is plausible that certain biomechanical and temporal constraints associated with digging, oviposition and nest closure activities negate any possibility for their improvement as the result of experience. It is also interesting to note that the specific acts that did show improvement (APP and ANP) are precisely those components that place the wasp in the greatest danger. Theraphosid spiders are formidable opponents and are capable of seizing and killing animals as large or larger than themselves including other spiders, scorpions, and solifugids, as well as small reptiles and mammals (Baerg 1958; Punzo & Henderson 1999). Thus, any capacity to reduce the time required to immobilize a spider should increase survivorship in these wasps.

In conclusion, the results of these experiments indicate that the hunting behavior of females of *P. cerberus* improves as a function of increasing encounters with a host. The significant decrease in the time allocated to the initial approach toward the host, as well as paralyzation, should result in a decrease in the amount of energy required to complete the overall hunting sequence. This should result in an increase in the energy available for other activities such as oogenesis, territorial defense, predator avoidance, and reproduction. This represents an optimization of foraging behavior and would increase the number of hosts that an individual wasp could locate within a given period of time.

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A COMPARISON OF BROOD STOCK ORIGIN FOR
EASTERN WILD TURKEY RESTORATION
IN EASTERN TEXAS

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Abstract.—It has been hypothesized that relocated eastern wild turkey (*Meleagris gallopavo silvestris*) brood stock obtained from similar ecological regions should survive and reproduce more successfully than stock obtained from dissimilar areas. Relocated eastern wild turkeys from midwestern (Iowa and Missouri) and south-eastern (east Texas and South Carolina) states were released into two study areas in the Post Oak Savannah of Texas during 1995-99. Prior to release, all birds were fitted with a radio transmitter and a leg band, and survivorship and reproduction monitored. There were no differences between midwestern (61%) and southeastern (49%) adult hen survival. Male survival, however, was greater for southeastern (90%) than for midwestern (64%) brood stock. Nesting rate, nest success, and hen success were similar for both hens of midwestern and southeastern origins. Because reproduction and adult hen survival were similar, yet male survival different based on brood stock origin, it is recommended that future reintroduction efforts consist of southeastern males with females coming from either brood stock.

Native populations of eastern wild turkeys (*Meleagris gallopavo silvestris*) in east Texas were limited to five isolated flocks numbering < 100 individuals in 1942 (Newman 1945). Initial restoration efforts using Rio Grande (*M. gallopavo intermedia*) and pen-raised turkeys in eastern Texas were unsuccessful (Newman 1945; Boyd & Oglesby 1975). In other southeastern states, restoration programs were successful using wild-trapped eastern wild turkeys (Kennamer & Kennamer 1990). Recent success by Texas Parks and Wildlife Department (TPWD) in obtaining wild-trapped birds from other states accelerated the statewide restoration program (Campo et al. 1984; Kennamer & Kennamer 1990). The majority of birds released in Texas restoration programs came from Iowa and Missouri and were released into habitats substantially different from their native ranges.

A total of 5,295 birds have been released into eastern Texas since 1979, with variable success (Burk pers. comm.). Studies

evaluating these releases were all restricted to the Pineywoods ecological region (Walker & Springs 1952; Gould 1975; Hopkins 1981; Campo 1983; Martin 1984). Recent restoration efforts (Lopez et al. 1998; Lopez et al. 2000) were extended into the Post Oak Savannah (POS) ecological region of Texas (Gould 1975), which is the historical western limit of this subspecies (Newman 1945, Gould 1975; Campo et al. 1984).

No reproductive success was observed in radio-marked eastern wild turkeys within the POS using midwestern brood stock since 1994 (Lopez et al. 1997; Lopez et al. 1998). Lopez et al. (1998; 1999) proposed limited nesting/brood habitat, insufficient stocking numbers, capture and handling methods, and radio-telemetry methodologies as factors potentially limiting the survival and growth of these populations. Further, TPWD and Texas A&M University personnel questioned whether birds of midwestern origin could acclimate to eastern Texas habitat and/or environmental conditions. Most states having viable eastern wild turkey populations used in-state brood stock for restoration efforts (Bailey 1973; Dickneite 1973; Dreis et al. 1973; Ignatoski 1973), although some successfully used birds from out of state (Wise 1973; Campo 1983). Prior to this study, there had been no trapping and relocation of eastern wild turkeys captured in Texas.

Objectives of this study were to compare survivorship and reproduction of eastern wild turkeys from midwestern (Iowa and Missouri) and southeastern (Texas and South Carolina) brood sources relocated into the POS of Texas. The authors predicted that birds obtained from southeastern states, introduced into the POS, would have greater survivorship and reproduction than birds from midwestern states.

MATERIALS AND METHODS

The Post Oak Savannah ecoregion of Texas is between the Pineywoods on the east, Blackland Prairies on the west, and Coastal Prairies and Marshes to the south (Gould 1975). The topography is gently rolling to hilly. Annual rainfall is 89-114 cm, with the high-

est rainfall month being May. Upland soils consist of sandy loams or sands over clay pans. Bottomland soils are sandy loams to clays. Overstory trees on the study areas were primarily post oak (*Quercus stellata*) and blackjack oak (*Q. marilandica*). Climax grasses included little bluestem (*Schizachyrium scoparium*), Indian-grass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), purpletop (*Tridens flavus*), and silver bluestem (*Bothriochloa saccharoides*). Some invasive plants included yaupon (*Ilex vomitoria*), broomsedge bluestem (*Andropogon virginicus*), bullnettle (*Cnidoscolus texanus*), and red lovegrass (*Eragrostis oxylepis*). All classes of livestock are grazed, but cattle are the most common (Gould 1975).

Release areas were chosen according to their ability to satisfy three requirements (Campo et al. 1989): (1) $\geq 2,023$ ha within a 4.8 km radius of the release site under a TPWD eastern turkey restoration license completed by all appropriate landowners, (2) $\geq 30\%$ woodland in the area, and (3) no wild turkey present. Two areas were selected for this study, one in the southern POS along the Brazos River in Washington and Waller counties, and the second in the northern POS in Anderson County. These study areas are approximately 450 km apart.

Eight female birds from Missouri were released at the Anderson County study area in 1995. Males were known to be on the area from a previous release, but all females released were dead at this time. Between January-March 1996, 21 (16 F, 5 M) wild-trapped eastern wild turkeys from Iowa and 18 (13 F, 5 M) from Texas were released into the Brazos River study area. In 1996 and 1997, 10 (6 F, 4 M) and 15 (12 F, 3 M) birds, respectively, from Iowa were added to the Anderson County study area. In 1997, an additional 15 (12 F, 3 M) birds from Missouri and 11 (all F) birds from South Carolina were released on the Brazos River study area. In 1998, another 8 (5 F, 3 M) birds from Iowa were released on the Brazos River study area. Twenty-five wild turkeys (18 F, 7 M)

from South Carolina were added to the Anderson County population in 1999.

All birds were fitted with a battery-powered mortality-sensitive radio transmitter (150-152 MHZ, 79-88 g, Advanced Telemetry Systems [ATS]; Inc. Isanti, Minn.) and TPWD numbered leg bands before release. Transmitters were attached as described by Williams et al. (1968) using elastic "shock" cord. All turkeys were aged and sexed (Pelham & Dickson 1992).

Location of each bird (primarily during the day) was attempted at least twice weekly during the entire study. Azimuths were taken to radio-marked birds from ≥ 3 known stations using a 5-element Yagi antenna mounted through the roof of a vehicle. Locations were determined by triangulation (White & Garrott 1990). To increase the precision of estimates, azimuths were taken perpendicular to one another when possible (Springer 1979). Further, readings for individuals were taken ≥ 24 hours apart so that locations were likely to be independent (Swihart & Slade 1985). During the nesting season (1 April-30 June), hens were monitored more intensively (3-4 days/week) to obtain nesting location.

Beginning 1 April of each year, hens were located three-four times weekly to determine nesting status. When triangulation indicated no movement for two consecutive tracking days, incubation was assumed to have begun. In approximately 10 days, nest locations were marked by circling the nest (≈ 50 m) and flagging the site to aid in later location. After a hen permanently left her nest, it was inspected to determine nest success (Glidden & Austin 1975; Vangilder et al. 1987; Vangilder & Kurzejeski 1995). Hens successfully hatching a clutch were located during roosting hours approximately two weeks post-hatch to determine poult survival. Reproductive parameters examined in this study (nesting rate, nest success, hen success, and poult mortality) were as described by Vangilder et al. (1987). Differences in nesting rates between brood stocks (adult hens) were compared using a Chi-square test (Ott 1993).

Annual survival was calculated for both areas using a percentage method (PM), thus comparisons could be made to other studies and radio-marked birds represented a population rather than a sample. For this study, censored animals or animals whose fates were unknown (i.e., radio transmitter failure, turkey losing radio transmitter, or a radio-marked turkey traveling beyond the study area) were not included in calculating survival (White & Garrott 1990). Hen comparisons used data from adults only because 8 juvenile hens were released during one year at a single study area (Anderson County in 1999) therefore comparisons could not be made. Survivorship between brood stocks (midwestern vs. southeastern) was compared by study area, sex, and by pooled study areas (study area differences were non-significant) using a Chi-square test for independence (Ott 1993). For these comparisons, statistical significance was accepted at $P < 0.05$.

RESULTS

There were no differences found between adult hen survival of midwestern ($\chi^2 = 0.083$, $df = 1$, $P = 0.774$) or southern ($\chi^2 = 0.407$, $df = 1$, $P = 0.527$) brood stock between the two study areas. Midwestern adult-hen survival was 62.3% ($n = 61$) in Anderson County and 59.6% ($n = 47$) at the Brazos River area (Table 1). For southern brood stock, adult hen survival was 40.0% ($n = 10$) in Anderson County and 51.4% ($n = 35$) at the Brazos River area. There was no difference between male survival of midwestern ($\chi^2 = 0.351$, $df = 1$, $P = 0.554$) or southern ($\chi^2 = 1.197$, $df = 1$, $P = 0.159$) brood stock between the two study areas. Midwestern male survival was 58.8% ($n = 17$) in Anderson County and 68.8% ($n = 16$) at the Brazos River area. For southern brood stock, male survival was 100% ($n = 7$) in Anderson County and 84.6% ($n = 13$) at the Brazos River area.

Because there was no difference in survival of adult females between sites, adult female data from both sites were pooled by

Table 1. Annual survival (percentage method, PM) and sample size (n) of eastern wild turkeys relocated into the Post Oak Savannah of Texas by study site, brood stock, and sex, 1995-99.

Study site Brood stock	Female		Male		Total	
	PM	n	PM	n	PM	n
Anderson County						
Midwestern	62	61	59	17	62	78
Southeastern	40	10	100	7	65	17
Pooled	59	71	71	24	62	95
Brazos River						
Midwestern	60	47	69	16	62	63
Southeastern	51	35	85	13	60	48
Pooled	56	82	76	29	61	111
Both Sites						
Midwestern	61	108	64	33	61	141
Southeastern	49	45	90	20	62	65
Pooled	58	153	74	53	62	206

brood stock. No difference ($\chi^2 = 1.942$, $df = 1$, $P = 0.163$) was found between survival of midwestern (61.1%; $n = 108$) and southern (48.9%; $n = 45$) brood stock. With no difference in adult female brood stock, data for all adult females were combined, resulting in an average survival of 57.5% ($n = 153$). However, pooled data by brood stock for males showed higher ($\chi^2 = 4.453$, $df = 1$, $P = 0.035$) survival for southern (90.0%; $n = 20$) as compared to midwestern (63.6%; $n = 33$) brood stock.

Although there was no difference ($\chi^2 = 0.211$, $df = 1$, $P = 0.646$) in adult hen nesting rates between study areas for midwestern birds, there was a difference ($\chi^2 = 5.657$, $df = 1$, $P = 0.017$) for southeastern birds. The nesting rate for midwestern birds in Anderson County and the Brazos River site was 82.1% ($n = 67$) and 78.4% ($n = 37$), respectively (Table 2). Similarly, nesting rates for southeastern birds were 40.0% ($n = 10$) in Anderson County and 80.8% ($n = 26$) at the Brazos River site. Because there were no differences in nesting rates between study areas for midwestern birds, data were

Table 2. Number of hens available to nest, number of nests, number of nest hatched, and number of poults produced to ≥ 2 weeks of age from adult eastern wild turkey hens relocated into the Post Oak Savannah of Texas by brood stock and study area, 1995-99.

Study site	Hens	Nests	Hatched	Poults
Brood stock				
Anderson County				
Midwestern	57	51	4	14
Southeastern	10	4	0	0
Pooled	67	55	4	14
Brazos River				
Midwestern	37	29	1	0
Southeastern	26	21	2	0
Pooled	63	50	3	0
Both Sites				
Midwestern	94	80	5	14
Southeastern	36	25	2	0
Pooled	130	105	7	4

pooled and the average nesting rate for midwestern birds averaged 80.8% ($n = 104$).

No difference was found in nest success for midwestern hens ($\chi^2 = 0.496$, $df = 1$, $P = 0.481$) or southeastern hens ($\chi^2 = 0.414$, $df = 1$, $P = 0.523$) between study sites. Nest success was 7% ($n = 55$) for midwestern hens in Anderson County and 3% ($n = 29$) at the Brazos River site, while for southeastern hens, it was 0% ($n = 4$) in Anderson County and 8% ($n = 21$) at the Brazos River Site (Table 2). When pooled between study sites, there was no difference ($\chi^2 = 0.073$, $df = 1$, $P = 0.787$) in nest success between adult hens from midwestern (6%; $n = 84$) and southeastern (8%; $n = 25$) brood stocks.

No hens from the Brazos River site produced young that survived to ≥ 2 weeks of age, whereas 3 hens from the Midwest released in Anderson County produced 14 poults that survived to ≥ 2 weeks (Table 2). Because of small sample sizes, these data could

not be tested statistically, but it did appear that poult production in the Anderson County site was better than the Brazos River site.

DISCUSSION

Annual survival of adult midwestern (PM = 61.1%) and southern (PM = 48.9%) hens did not differ statistically and their pooled weighted average (PM = 57.5%) was comparable to rates reported elsewhere (PM range 50-63%) for established and restocked populations (Everett et al. 1980; Campo et al. 1984; Kurzejeski et al. 1987; Little et al. 1990; Palmer et al. 1993; Roberts et al. 1995; Vangilder & Kurzejeski 1995; Wright et al. 1996; Lopez et al. 1998).

Annual survival for both midwestern (PM = 63.6%) and southern (PM = 90.0%) gobblers was comparable to other established and restocked populations of gobblers (PM range 71-100%) (Everett et al. 1980; Campo et al. 1984), and higher than reported by Lopez et al. (1998) (PM = 36%) for first-year males in the POS.

Mean weighted nesting rates for midwestern hens for both areas were 80.8%, as was the nesting rate for southeastern hens at the Brazos River site. However, the nesting rate for southeastern hens in Anderson County (40.0%) was similar to that (43%) reported by Lopez et al. (1998) in the POS, but lower than reported in other studies (81-100%) for established and restocked populations (Glidden & Austin 1975; Porter et al. 1983; Campo et al. 1984; Vangilder et al. 1987; Vander Haegen et al. 1988; Vangilder & Kurzejeski 1995). The low nesting rate for southeastern hens in Anderson County might be a result of small sample sizes, as only 10 southeastern hens survived to the nesting season. Because the southeastern hens at the Brazos River site exhibited the same nesting rate as midwestern hens, the authors believe that nesting rates were probably similar for each brood stock.

Nest success for adult midwestern hens (6%) and southeastern hens (8%) was lower than reported (25% juvenile, 29% adult) by Lopez et al. (1998) in the POS, and lower than reported in other studies (30-73%) for established and restocked populations (Glidden & Austin 1975; Porter et al. 1983; Campo et al. 1984; Vangilder et al. 1987; Vangilder & Kurzejeski 1995).

The low hen success for this study (2%) was similar to the figures that Lopez et al. (1998) reported (0%) for the POS, but lower than typically seen for adults (35–68%) and juveniles (30–61%) in other studies (Glidden & Austin 1975; Hon et al. 1978; Everett et al. 1980; Pack et al. 1980; Porter et al. 1983; Campo et al. 1984; Holbrook et al. 1987; Vangilder et al. 1987; Vander Haegen et al. 1988; Vangilder & Kurzejeski 1995). Campo et al. (1984) and Lopez et al. (1999) suggested that inadequate availability of nesting/brood habitat in the POS of Texas limits wild turkey production and recruitment in this region. Historically, the POS was maintained by wildfire. However, brush encroachment (e.g., yaupon) in forested areas, and increased grazing pressure (Allen 1974; Smeins & Diamond 1986) has reduced suitable nesting and brood-rearing habitat. Higher nest predation and poult mortality is expected when nesting and brood-rearing habitat is limited (Haensly et al. 1987; Seiss et al. 1990; Badyaev 1995; Lopez et al. 1997). It is proposed that nesting and brood-rearing habitat must be improved in the POS of Texas if eastern wild turkey stocking is to be successful.

No differences were found in mortality and reproduction between relocated midwestern and southeastern adult wild turkey hens. However, males from southeastern states survived better than males from midwestern states. Lopez (1996) suggested that midwestern males did not avoid forested habitats with a dense yaupon understory, thus exposing them to bobcat (*Felis rufus*) and canid (*Canis*) predation. Southeastern males, however, being familiar with this habitat, had greater survival rates. Therefore, it is proposed that restocking efforts in the POS of Texas could use either midwestern or southeastern adult hens for restocking, but that only southeastern males should be used in these efforts.

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A TROPICAL WEATHER VULNERABILITY ASSESSMENT FOR TEXAS COASTAL COUNTIES

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Abstract.—A Tropical Weather Vulnerability Index is developed for the Texas coast. This index is based on the Hurricane Vulnerability Index of Dixon & Fitzsimons (2001), but includes additional data on tropical storms and accounts for edge effects of storms making landfall in Louisiana or Tamaulipas. The Index includes risk and exposure. Risk is measured by the number of landfalling tropical storms and hurricanes on Texas coastal counties. Exposure is measured by the number of people and the amount of property in these counties. Analysis shows the northern part of the coast, particularly Harris, Galveston, and Brazoria counties, to be more vulnerable than the central and southern parts.

In recent decades hurricane related fatalities in the United States have dropped due to improvements in forecasts, disaster preparedness, and public awareness. At the same time, there has been an increase in damages due to an increase in coastal population and property. This increase in property damage has taken place during a relatively quiet period in terms of hurricane frequency (Franklin et al. 2003).

The same trends are true for Texas coastal counties (Figure 1), making them increasingly vulnerable to hurricanes (Dixon & Fitzsimons 2001). Given that there are over 5 million residents in Texas coastal counties, and property valued at over 300 billion dollars, coastal counties are particularly vulnerable to tropical storms and hurricanes. This paper follows the method used in Dixon & Fitzsimons (2001) to quantify the vulnerability of Texas coastal counties to tropical activity, both hurricanes and tropical storms. The index has also been corrected for edge effects, by including data from Cameron Parrish, Louisiana and Matamoros, Tamaulipas, Mexico.

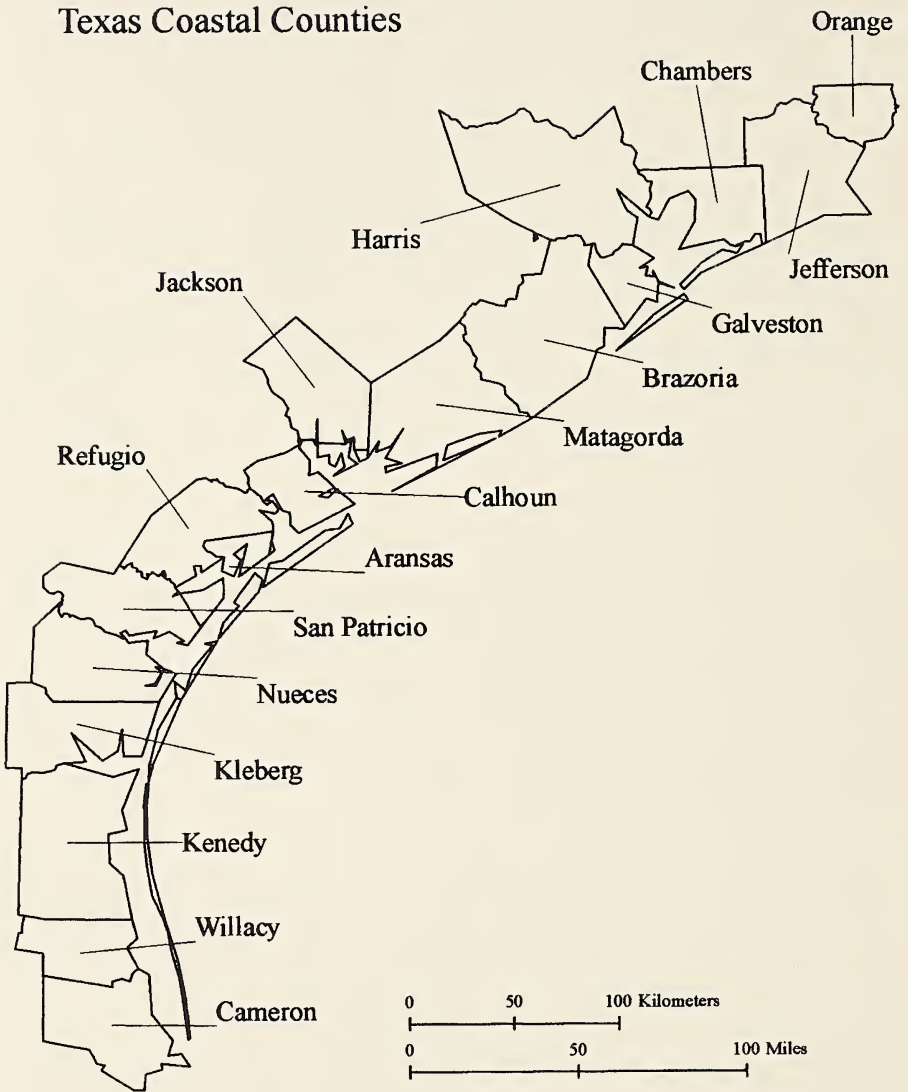


Figure 1. Map of Texas coastal counties.

TEXAS TROPICAL WEATHER CLIMATOLOGY

Hurricane intensity is measured with the Saffir-Simpson scale. There are five categories for hurricanes. The potential damage associated with these hurricanes increases from minimal (Category 1) to extreme (Category 5) with increasing wind strength. Tropical storms which range in wind speed from 39 – 73 mph can be considered Category 0 systems in the Saffir-Simpson scale but are also capable of doing significant damage. For example, Tropical Storm Allison (1989) caused over 5 billion dollars in damage in Houston and the surrounding area, more than twice the damage caused by Texas' costliest hurricane, Alicia, that hit Galveston in 1983 (National Weather Service 2004). Serious threats from tropical activity include the flooding caused by extreme rainfall and coastal storm surges. Although the traditional tropical weather season runs from June through November, tropical storms and some hurricanes have been observed in May and December. Both types of storm are most common in September (Landsea 1993).

Proxy records from lake and marsh sediments as well as historical records indicate tropical activity has affected the United States and Gulf Coast throughout most of the past (Elsner et al. 2000; Herrera et al. 2003). However, reliable instrumental data have existed for only about the last century. Although there is evidence of cycles of hurricane activity, Gulf landfalling hurricanes have not increased significantly in frequency or intensity over the past century (Bove et al. 1998). Hurricanes that enter the Gulf of Mexico tend to be stronger than those that affect the East Coast and their strength can be affected by both the Southern Oscillation (SOI) and North Atlantic Oscillation (NAO). In years when a La Niña (positive SOI) is in progress, and when the NAO is negative, Gulf hurricanes can become more intense (Elsner 2003). On average hurricanes strike the Texas coast every 6 years. Since 1900, 36 hurricanes and 27 tropical storms have made landfall on the Texas coast. Dixon & Fitzsimons (2001) include a list of landfalling Texas hurricanes through 1999. One additional hurricane, Claudette, a Category 1 in July 2003, has made landfall in Calhoun

Table 1. Texas tropical storms.

Year	Month	Name	Landfall County
1901	July		Matagorda
1910	September		Kenedy
1925	September		Cameron
1931	June		Kenedy
1933	July		Matagorda
1936	September		Cameron
1938	October		Brazoria
1941	September		Jefferson
1958	September	Ella	San Patricio
1960	June		Kleberg
1964	August	Abby	Matagorda
1968	June	Candy	Refugio
1970	September	Felice	Chambers
1971	September	Fern	San Patricio
1973	September	Delia	Brazoria
1978	August	Amelia	Cameron
1979	July	Claudette	Jefferson
1979	September	Elena	Matagorda
1980	September	Danielle	Galveston
1987	August		Galveston
1989	June	Allison	Matagorda
1998	August	Charley	San Patricio
1998	September	Frances	Aransas
2001	September	Allison	Brazoria
2002	August	Bertha	Kleberg
2002	September	Fay	Calhoun
2003	August	Grace	Galveston

Source: National Hurricane Center

Table 2. Number of tropical system impacts by county.

County	Saffir-Simpson Intensity Category					Impact Score
	0	1	2	3	4	
Aransas	7	4	3	1	1	51
Brazoria	11	6	2	4	3	111
Calhoun	7	3	2	1	1	45
Cameron	4	1	0	3	0	30
Chambers	6	6	1	1	4	94
Galveston	6	6	1	3	3	94
Harris	2	3	0	1	0	16
Jackson	1	1	0	0	1	19
Jefferson	10	5	4	0	2	68
Kenedy	5	1	0	3	2	63
Kleberg	4	3	2	3	1	58
Matagorda	8	4	3	3	1	68
Nueces	4	3	2	1	0	26
Orange	6	4	4	0	2	62
Refugio	6	3	0	0	1	28
San Patricio	4	2	2	1	0	24
Willacy	6	0	0	5	1	62

County, Texas. Table 1 lists landfalling tropical storms recorded from 1900 to 2003. Landfall County is defined as the county in which the eye of the storm crosses the coast.

MATERIALS AND METHODS

Vulnerability includes both risk and exposure (Pielke & Pielke 1997). The tropical weather vulnerability index presented here is constructed in the same way as the hurricane vulnerability index in Dixon & Fitzsimons (2001) except that the period of record has been extended through 2003. To construct the risk portion of the

Table 3. Population and property values for Texas coastal counties.

County	2000 Population	1997 Property Value (\$)
Aransas	22,497	1,524,287,515
Brazoria	241,767	17,049,533,334
Calhoun	20,647	3,945,104,263
Cameron	335,227	9,917,486,101
Chambers	26,031	4,674,961,510
Galveston	250,158	14,838,869,994
Harris	3,400,578	205,039,931,976
Jackson	14,391	1,207,493,949
Jefferson	252,051	15,306,548,750
Kenedy	414	559,584,670
Kleberg	31,549	1,373,335,780
Matagorda	37,957	3,073,275,066
Nueces	313,645	14,015,499,813
Orange	84,966	4,073,340,476
Refugio	7,828	749,285,130
San Patricio	67,138	2,862,810,475
Willacy	20,082	688,714,131

Sources: US Bureau of the Census and Texas State Property Tax Board

index, any county experiencing a landfalling hurricane or tropical storm and those counties immediately adjacent to it are assigned an impact score of 2^n where n is the Saffir-Simpson scale rating of the storm. The National Hurricane Center best track database is used for landfall county determination. These scores are then normalized, ranked, classified into six categories and reassigned scores of 2^n where n is the class number. Without this correction impact scores would be expected to grow over time as areas are subjected to additional storms. The number of tropical storm and hurricane impacts and impact scores for each county are given in Table 2.

Table 4. Tropical Weather Vulnerability Index (TVI) by county.

County	Tropical Risk	Population Exposure	Property Exposure	TVI
Aransas	8	2	2	12
Brazoria	32	16	16	64
Calhoun	8	2	8	18
Cameron	4	16	16	36
Chambers	32	2	8	42
Galveston	32	16	16	64
Harris	1	32	32	65
Jackson	1	2	2	5
Jefferson	16	16	16	48
Kenedy	16	1	1	18
Kleberg	16	4	2	22
Matagorda	16	4	4	24
Nueces	2	16	16	34
Orange	16	8	8	32
Refugio	4	1	1	6
San Patricio	2	8	4	14
Willacy	16	2	1	19

To construct the exposure portion of the index, which has both a population and property component, population and property values are ranked, also classified into six categories and assigned scores of 2ⁿ where n is the class number. Data for 2000 population and 2003 property values were obtained from the Census Bureau and the State Property Tax Board. Raw values used in this analysis are listed in Table 3.

RESULTS AND DISCUSSION

The Tropical Weather Vulnerability Index is calculated by summing the risk, population exposure and property exposure scores.

Texas Tropical Vulnerability Index

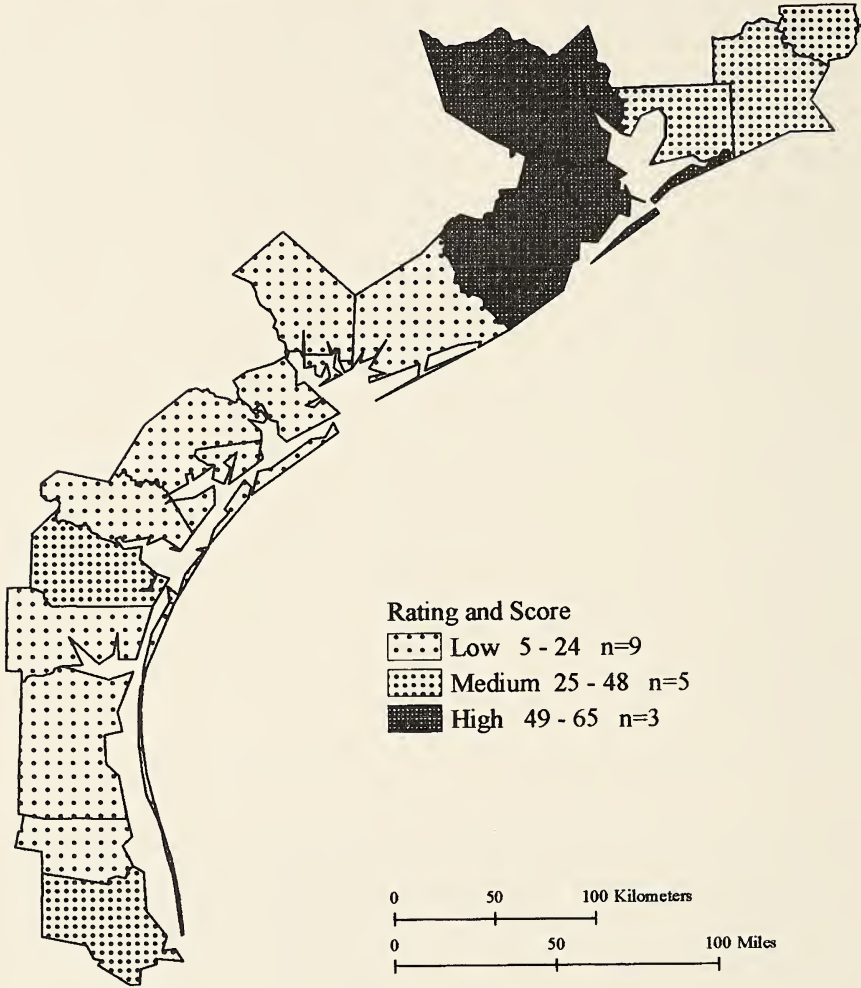


Figure 2. Map of Texas Tropical Vulnerability Index for coastal counties.

These data are given in Table 4. When interpreting the TVI attention should be paid to all the components. For example, a county with high population and/or high property values but a

relatively low risk would still receive a high TVI. Thus the TVI identifies not only areas of current risk but those in which a relatively low probability event could have significant impact. The final index scores are then classified into three categories representing low, moderate and high vulnerability. When these rankings are mapped, as in Figure 2, it is clear that about half of the Texas coast has a low vulnerability, and half possesses a moderate or high vulnerability. The northern part of the coast is the most vulnerable, particularly Harris, Galveston, and Brazoria counties, including the cities of Houston, Galveston, and Freeport. By adding data for tropical storms and adjacent counties in Louisiana and Mexico, and including data up to 2003, this study slightly changes the resulting map from that presented in Dixon & Fitzsimons (2001). Vulnerability is higher in Orange County, the northernmost of the Texas coastal counties.

This paper updates the Hurricane Vulnerability Index developed by Dixon & Fitzsimons (2001) into a Tropical Weather Vulnerability Index that also accounts for tropical storms and edge effects in the data. The addition of tropical storm data does not greatly change the pattern of vulnerability shown by the original index, and the increased vulnerability noted for Orange County is due to the addition of data from Cameron County, Louisiana. Although it does not take into account specific hazards associated with hurricanes or tropical storms, the Tropical Weather Vulnerability Index can be easily calculated and updated in a spreadsheet package and GIS. It is the intent of the authors that this will make it useful for planning and mitigation purposes along the Texas Coast.

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GENERAL NOTES

NOTES ON REPRODUCTION IN THE
MEXICAN WEST COAST RATTLESNAKE,
CROTALUS BASILISCUS (SERPENTES: VIPERIDAE)**Stephen R. Goldberg, Kent R. Beaman and Eric A. Dugan***Department of Biology, Whittier College**Whittier, California 90608**Section of Herpetology, Natural History Museum of Los Angeles County**Los Angeles, California 90007**Department of Natural Sciences, Loma Linda University**Loma Linda, California 92350*

The Mexican west coast rattlesnake, *Crotalus basiliscus*, occurs from the Río Fuerte drainage in extreme southern Sonora, Mexico, southward along the coastal plain, foothills, and valleys of Sinaloa, Nayarit, Jalisco, Colima, and northwestern Michoacán (Campbell & Lamar 2004). This species inhabits thornforest, tropical deciduous forest, and the ecotonal belt between tropical deciduous forest and pine-oak forest (Campbell & Lamar 2004).

The biology of *C. basiliscus* was summarized by McCranie (1981). Information on various aspects of reproduction appeared in Perkins (1943), Marcy (1945), Hardy & McDiarmid (1969), and Klauber (1972). Herein, additional information is provided on the reproductive cycle of *C. basiliscus* from field observations and a histological examination of gonadal material from museum specimens.

Forty-four specimens of *C. basiliscus* (six females, mean snout-vent length, [SVL] = 1003 mm $\pm$ 214 *SD*, range: 805-1280 mm; six males, SVL = 970 mm $\pm$ 156 *SD*, range: 760-1225 mm; and 32 juveniles, SVL = 317 mm $\pm$ 24 *SD*, range: 285-395 mm) were examined from the herpetology collections of the California Academy of Sciences, San Francisco (CAS) and Natural History Museum of Los Angeles County, Los Angeles (LACM). The left testis and vas deferens were removed from males and the left ovary was removed from females for histological examination. Enlarged

follicles or oviductal eggs were counted but not removed for examination. Tissues were embedded in paraffin, sectioned at 5 μm and stained with Harris' hematoxylin and eosin counterstain. Using prepared slides, testes were examined to determine the stage of the male cycle and ovaries for the presence of yolk deposition (secondary vitellogenesis, *sensu* Aldridge 1979). To assess date of parturition, mean body sizes of *C. basiliscus* juveniles collected from July were compared to those from August using an unpaired *t*-test.

Material examined.—The following specimens of *Crotalus basiliscus* were examined: JALISCO (CAS 74403), MICHOACÁN (CAS 147400), NAYARIT (LACM 37330, 51569, 104447), SINALOA (CAS 24095, 95765, 159398, 159399, LACM 7197, 7198, 7200-7222, 59183, 104449, 104450, 104452, 104453, 104456, 115989, 115990), and SONORA (LACM 104459, 104461).

The seminiferous tubules of CAS 159399 (SVL 980 mm, collected 20 April 1962) were regressed with a few clusters of sperm from spermiogenesis of the previous year, spermatogonia, and Sertoli cells. The vas deferens was packed with spermatozoa. Seminiferous tubules of CAS 74403 (SVL 1225 mm, collected May 1922) were regressed; the vas deferens was not available. Seminiferous tubules of LACM 7222 (SVL 760 mm, collected 3 July 1962) were regressed and contained spermatogonia and Sertoli cells; the vas deferens was not available. Seminiferous tubules of CAS 24095 (SVL 1005 mm, collected 1 July 1963) were in recrudescence (i.e., renewal of germinal epithelium for the next period of spermatogenesis and then spermiogenesis). Primary and secondary spermatocytes as well as spermatids (no spermatozoa) were present in the latter specimen; the vas deferens contained spermatozoa. Seminiferous tubules in two males from December CAS 147400 (SVL 866 mm, collected 24 December 1976) and LACM 104456 (SVL 985 mm, collected 16 December 1962) were undergoing spermiogenesis. Lumina of the seminiferous tubules were lined by spermatozoa and rows of meta-

morphosing spermatids. The vasa deferentia were packed with spermatozoa. This suggests that the testicular cycle of *C. basiliscus* is similar to that of other North American rattlesnakes in that spermatozoan formation occurs during late summer and autumn (Aldridge & Brown 1995; Goldberg 1999a; 1999b; 1999c; 2000a; 2000b; 2000c; 2002; 2004; Goldberg & Beaman 2003a,;2003b; Goldberg & Holycross 1999; Goldberg & Rosen 2000; Holycross & Goldberg 2001; Rosen & Goldberg 2002).

Five females contained inactive ovaries consisting of small follicles that were not undergoing yolk deposition: CAS 159398 (SVL 815 mm, collected 20 April 1962); LACM 104449 (SVL 805 mm, collected 10 June 1957); CAS 95765 (SVL 1258 mm, collected 16 July 1964); LACM 7201 (SVL 900 mm, collected 18 July 1962); LACM 7200 (SVL 960 mm, collected 22 August 1962). One female, LACM 7219, (SVL 1280 mm, collected 27 July 1962) contained 12 oviductal eggs.

Ramírez-Bautista (1994) and Klauber (1972) reported litter sizes for *C. basiliscus* of 24-35 and 33.2 ± 12.7 *SD* (range: 14-60, *n* = 13), respectively. The 12 oviductal eggs from LACM 7219 represent a new minimum litter size for *C. basiliscus*. The presence of adult females in spring with ovaries that were not undergoing yolk deposition suggests that not all *C. basiliscus* females produce young each year. This occurs in other southwestern North American rattlesnakes where production of young appears related to abundance of food, resulting in a less-than-annual reproductive cycle (Goldberg & Rosen 2000; Rosen & Goldberg 2002; Taylor & DeNardo 2005). Ramírez-Bautista (1994) reported mating occurred in June in the year prior to parturition, thus also, suggesting a less-than-annual reproductive cycle for *C. basiliscus*. Further study is needed to ascertain the frequency at which populations of *C. basiliscus* produce young.

One of us (EAD) observed a *C. basiliscus* neonate on 10 July 2004 at Alamos, Sonora (27°10'N, 108°55'W). Hardy & McDiar-

mid (1969) reported a litter of 20 neonates from near Escuinapa, Sinaloa (22°85' N, 105°80' W), collected 27 July 1962, of which 17 were deposited in LACM (mean SVL = 307 mm $\pm$ 8 *SD*, range: 295-320 mm); a specific date of parturition is unknown. Juveniles from July measured 309 mm SVL $\pm$ 14 *SD* (range 290-360 mm, *n* = 22) and August juveniles measured 332 mm SVL $\pm$ 35 *SD* (range 285-395 mm, *n* = 9). The August sample was significantly larger than that from July (*t* = 2.71, *df* = 29, *P* = 0.011) suggesting that growth was underway and that parturition had occurred in July concomitant with the onset of the summer monsoon. The appearance of young with the onset of the rainy season was previously reported for *C. basiliscus* by Ramírez-Bautista (1994). However, Hardy & McDiarmid (1969) observed neonate *C. basiliscus* through late September in Sinaloa. One juvenile from 11 September 1967 (LACM 51569) measured 345 mm SVL (388 mm total length, TL). It showed evidence of a post-neonatal shed (a rattle with a button and one segment). The smallest *C. basiliscus* reported by Klauber (1972) measured 296 mm TL, with an average size at birth of 330 mm TL.

This study indicates that the reproductive cycle of *C. basiliscus* is similar to that of other rattlesnakes from North America. Males produce sperm during late summer to autumn, with storage in the vasa deferentia occurring into spring. Only some females produce young each year.

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NOTEWORTHY RECORDS OF THE EASTERN PIPISTRELLE,
PERIMYOTIS SUBFLAVUS, AND SILVER-HAIRED BAT,
LASIONYCTERIS NOCTIVAGANS, (CHIROPTERA: VESPERTILIONIDAE)
FROM THE CHISOS MOUNTAINS, TEXAS

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Twenty species of bats have been documented from Big Bend National Park (Easterla 1973; Higginbotham et al. 1999; Higginbotham & Ammerman 2002), however the occurrence of one of these, *Lasiurus borealis*, has been questioned (Easterla 1975). Most netting efforts have been conducted at the lower elevations in the park, but a few investigators have examined the bat species occurring in the Chisos Mountains (Borell & Bryant 1942; Easterla 1973). The Chisos Mountains, within Big Bend National Park (BBNP), range up to 7835 ft (2388m) elevation at the highest peak. The vegetation is dominated by a woodland plant association (pinyon/juniper/oak), however some moist canyons support a cypress/pine/oak association (Wauer 1971). This report documents the occurrence of *Perimyotis (Pipistrellus) subflavus* and *Lasionycteris noctivagans* in a moist woodland canyon of the Chisos Mountains (Brewster County, Texas) and brings the total diversity of bats in Big Bend National Park to 22 species – one of the highest for any national park.

One adult male eastern pipistrelle, *Perimyotis subflavus*, and two adult male silver-haired bats, *Lasionycteris noctivagans*, were collected by mistnet on 22 May 2004. Use of the genus *Perimyotis* instead of *Pipistrellus* follows the recommendation of Menu (1984) and Hooper & Van Den Bussche (2003). Both species were collected at 2097m (6880 ft) elevation over pools in Boot Spring drainage (UTM 13R 0665488E 3235919N) in the Chisos Mountains. These three individuals were the first captured that evening (between 2110 and 2130h). Specimens were deposited in the Angelo State Natural History Collection (*Perimyotis subflavus*,

ASNHC 12899; *Lasionycteris noctivagans*, ASNHC 12897 and 12898) and tissues were deposited in the Angelo State Natural History Frozen Tissue Collection (*P. subflavus*, ASK 6764; *L. noctivagans* ASK6765, 6766). According to Schmidly (2004) these species are uncommon in the Trans-Pecos and have not been documented in BBNP or Brewster County, Texas. Therefore, these specimens represent new records for Brewster County.

Perimyotis subflavus is known primarily from the eastern two-thirds of Texas (Schmidly 2004) but Yancey et al. (1995) captured a single male in July 1994 in riparian habitat in Presidio County. This species is known to forage along wooded waterways early in the evening (Fujita & Kunz 1984) and Baker (1956) speculated that this species might use the Rio Grande as a corridor to disperse into Coahuila, Mexico. This explanation could also apply to the unusual records for *P. subflavus* in the Trans-Pecos region of Texas. The species may have dispersed from the Rio Grande northward into riparian zones at relatively high elevations. Yancey (1997) did not report the specific elevation at which *P. subflavus* was captured, however he stated that the site was in the foothills of the Chinati Mountains close to, but not above, 1500m. The capture of *P. subflavus* in the Chisos Mountains at 2097m is the highest reported elevation for this species.

Although, *Pipistrellus hesperus* (western pipistrelle) and *P. subflavus* generally are thought to be allopatric (Fujita & Kunz 1984) or to partition habitat (Baker 1956), both species were captured at the same site on the same night. This report agrees with Yancey et al. (1995) and Dowler et al. (1992) who also found these two species together. Based on work in Coahuila, Baker (1956) suggested that *P. subflavus* was restricted to large trees (pecan, cypress, and willow) along permanent streams while *P. hesperus* lived in the lowland desert and mountainous regions. Fujita & Kunz (1984) reported that solitary individuals of *P. subflavus* are known to roost in trees in summer, but more commonly roost in caves and man-made structures, especially during hibernation. In

contrast, *P. hesperus* roosts in cracks and crevices of canyon walls (Schmidly 2004). Both roosting habitats are available in Boot Canyon. In fact, it might be ecologically important that *P. subflavus* was captured near a relict population of Arizona cypress (*Cupressus arizonica*).

The discovery of two male *L. noctivagans* at high elevation in the Chisos Mountains in Brewster County was not unexpected. In fact, Easterla (1973) predicted that *Lasionycteris* might occur in BBNP and listed it as a hypothetical species. Male silver-haired bats have also been reported in west Texas in spring and fall (Terrell and Presidio Counties; Schmidly 1991; Dowler et al. 1992; Ammerman et al. 2002) but not in Brewster County. It is difficult to determine if the *Lasionycteris* specimens that were captured in late May in Brewster County are migrants or residents. *Lasionycteris* is generally thought to be absent from Texas in the summer but one mid-summer record in the Guadalupe Mountains (Schmidly 2004) to the north of BBNP suggests that individuals might spend the summer months in the Chisos Mountains as they do in mountains of the western United States (Cryan 2003). Additionally, Cryan (2003) reported that female silver-haired bats are generally absent from mountainous regions of western North America during summer so the presence of males in the Chisos Mountains of west Texas is consistent with this pattern. Contrary to previous reports that this species flies late (Kunz 1982), both males were captured early in the evening. Adams (2003) and Whitaker et al. (1977) also have observed an early activity pattern for *L. noctivagans*.

Along with *P. subflavus* and *L. noctivagans*, a total of 35 bats of 10 species were captured at the same site on the same night. Other bats captured were (number of males/ number of females): *Eptesicus fuscus* (8/0), *Myotis californicus* (2/1), *Myotis thysanodes* (3/0), *Myotis volans* (1/2), *Antrozous pallidus* (5/0), *Corynorhinus townsendii* (0/6), *Lasiurus cinereus* (3/1), and *Pipistrellus hesperus* (1/0). Most individuals (25 out of 35) were male. The same

locality was sampled previously on 23 May 1999 and 29 July 2002 and five species (16 individuals) were captured. The majority of these captures also were males (except for two *C. townsendii* and two *M. volans* females). A male sex bias also was observed by Easterla (1973) at the same site during his work between 1967-1971. Easterla documented 13 species at Boot Spring and 80% (124/155) of the bats of known sex were males. Cryan (2003) showed that within species of tree bats (*Lasiurus* and *Lasionycteris*), sexes segregate and males occupy the habitats at higher elevations in the summer. This study supports this pattern and suggests that it may apply more generally to other bat species. The significance of this phenomenon remains unknown, but likely reflects the physiological requirements of female bats during reproduction (Racey & Entwistle 2000).

The documentation of *P. subflavus* and *L. noctivagans* from the Chisos Mountains of west Texas is consistent with the discovery that other "eastern" bats (such as *Nycticeius humeralis*, *Lasiurus seminolus*) appear to be moving westward (Yancey et al. 1995; Dowler et al. 1999; Brant & Dowler 2000). Although it could be argued that these apparent distributional shifts are the result of an increase in survey effort in the western portion of the state, this may not provide an adequate explanation for the records reported herein. The same site was sampled six times by Easterla (1973) over the course of five years (during the summer months), and three times by the author over the last six years, before these species were discovered. An alternative explanation, and one that has been proposed to explain some recent distribution changes in Texas and Costa Rica (Brant & Dowler 2000; LaVal 2004), is that global climate change is driving the shift. Scheel et al. (1996) modeled environmental changes in Texas that would accompany global warming and one of their predictions was that tree-roosting bats would expand into more western habitats. This current study supports this hypothesized trend; the extent of which will only be understood with additional inventory and monitoring efforts.

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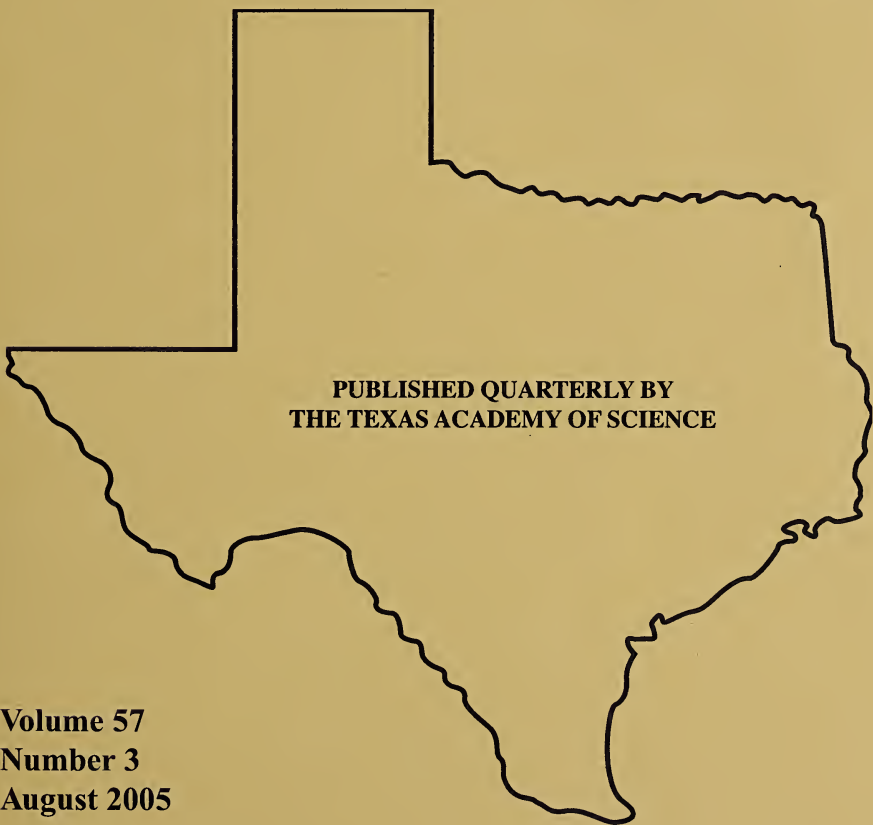


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RANGE EXTENSIONS AND COUNTY RECORDS FOR
ANGIOSPERMS FROM THE SOUTHWESTERN CROSS TIMBERS
IN EASTLAND COUNTY, TEXAS

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Abstract.—This study reports the results of fieldwork conducted during June–August 2002 and February–May 2003 on a privately owned ranch in the southwestern Cross Timbers region of north central Texas. A total of 150 species of flowering plants in 55 families are reported with 72 species in 44 families representing new distribution and occurrence records for Eastland County. Seven of these records represent major range extensions for the species in Texas.

The flora of the southwestern Cross Timbers region of Texas is poorly known as compared to other regions of North Central Texas (Turner et al. 2003a; 2003b). The southwestern Cross Timbers is that part of the West Cross Timbers (Diggs et al. 1999) that encompasses Brown, eastern Callahan, Comanche, Eastland, Erath, Palo Pinto, eastern Shackelford, and Stephens counties in Texas. Soils are often sandy or sandy clays, rainfall is about 60–80 cm per year, and there are about 230 frost free days in the year (Diggs et al. 1999). Pre-settlement vegetation was likely savannah with post oak overstory and an understory dominated by little bluestem (Dyksterhuis 1948). At present, because of fire suppression, brush such as mesquite and cedar are increasing and suppressing the original grassland component (Diggs et al. 1999).

STUDY AREA AND METHODS

The McPhail Land and Cattle Company is a 10,750 ha ranch located in the southwestern Cross Timbers in Eastland County, Texas (Figure 1). The ranch has a diversity of habitats including rocky Cretaceous outcrops and the Leon River bottomlands. Typical habitats found on the ranch include clayey bottomlands, disturbed areas, lacustrine areas around ponds and lakes, grasslands, riparian areas immediately adjacent to the river, rocky outcrops or gravelly slopes, and sandy woodlands. Average precipitation in this

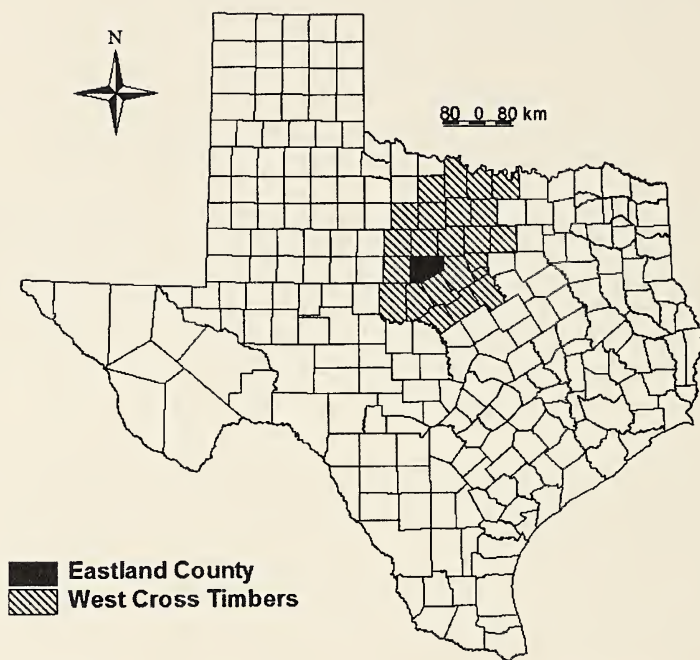


Figure 1. Map of Texas showing the location of all counties that contain portions of the West Cross Timbers.

region of the West Cross Timbers is about 65 cm and is usually concentrated in the spring and fall (Diggs et al. 1999).

Floristic surveys on the ranch were conducted in the June-August 2002 and February-May 2003. Sampling was done by randomly selecting different vegetational areas throughout the ranch and collecting at least every 10 days by walking, driving, or horseback. Plants were identified using *Shinners and Mahler's Illustrated Flora of North Central Texas* (Diggs et al. 1999). Nomenclature of native or naturalized plants was standardized using Jones et al. (1997; 2003). Taxa are discussed alphabetically according to family. Voucher specimens are deposited in the Tarleton State University Herbarium (TAC).

RESULTS AND DISCUSSION

The survey resulted in 150 species in 55 families. The Asteraceae (21 species), Fabaceae (14 species), Poaceae (9 species), and Onagraceae (8 species) were the most numerous families. This analysis resulted in new distribution and occurrence records for 72 species from Eastland County in relation to information currently available in the *Atlas of the Vascular Plants of Texas* (Turner et al. 2003a; 2003b). Ninety-one percent of the total number of plants surveyed and 83% of the distributional records were native species. Sixty-three species represent new county records for Eastland County but also have been reported (Turner et al. 2003a; 2003b) to occur in counties bordering Eastland County (Table 1).

None of the species reported are federally-listed noxious weeds (Plant Protection and Quarantine (PPQ) 2002; United States Department of Agriculture, Animal and Plant Health Inspection Service, PPQ 2003). Several weedy species that had previously been reported from only one county in the southwestern Cross Timbers (Turner et al. 2003a; 2003b) are worth further comment. The following species (Table 1) had previously been reported only from Brown County (Turner et al. 2003a) in the southwestern Cross Timbers. *Amaranthus rudis* is an invader species of low moist, disturbed sites and is found nearly throughout Texas (Diggs et al. 1999) and was collected bordering a pond on the ranch. *Ambrosia trifida* is often extremely abundant in disturbed areas nearly throughout the state (Diggs et al. 1999). It was collected in the Leon River bottom from the ranch. *Grindelia papposa* is found in disturbed areas and is widespread in Texas. It was collected in disturbed areas on the ranch. *Funastrum cynanchoides* is known from waste places with sandy or rocky soils mainly in the western one-half of Texas (Diggs et al. 1999). It was collected in the clay-soiled bottomlands of the Leon River on the ranch. *Campsy radicans* occurs along stream banks, disturbed ground, along fences, and is cultivated and may escape becoming a problematic weed in the eastern half of Texas (Diggs et al. 1999). Collection of

Table 1. Floral records for Eastland County that have also been reported from bordering counties (Turner et al., 2003a; 2003b) including Brown (B), Callahan (CA), Comanche (CO), Erath (E), Palo Pinto (P), Shackelford (SH), and Stephens (ST). Plants that are native (N) to north central Texas and introduced (I) are indicated.

Family	Species	Bordering Counties	N/I
Amaranthaceae	<i>Amaranthus rudis</i> J.D. Sauer	B	N
Amaryllidaceae	<i>Cooperia drummondii</i> Herb.	B	N
Anacardiaceae	<i>Rhus lanceolata</i> (A. Gray) Britton	B,CA,CO,E,P	N
Apiaceae	<i>Torilis arvensis</i> (Huds.) Link	B,P	I
Asclepidaceae	<i>Funastrum cynanchoides</i> (Decne.) Schltr.	B	N
Asteraceae	<i>Ambrosia trifida</i> L. var. <i>texana</i> Scheele	B	N
	<i>Conyza canadensis</i> (L.) Cronquist		
	var. <i>glabrata</i> (A. Gray) Cronquist	B,C	N
	<i>Dyssodia pentachaeta</i> DC.	B	N
	<i>Erigeron strigosus</i> Muhl. ex Willd.	B,CA,E	N
	<i>Grindelia papposa</i> G.L. Nesom & Y.B. Suh	B	N
	<i>Senecio ampullaceus</i> Hook.	CA,CO	N
	<i>Symphotrichum subulatum</i> (Michx.) G. L. Nesom	B,E,P	N
Bignoniaceae	<i>Campsis radicans</i> (L.) Seem. ex Bureau	B	N
Brassicaceae	<i>Sibara virginica</i> (L.) Rollins	CA	N
Capparaceae	<i>Polanisia dodecandra</i> (L.) DC.		
	subsp. <i>trachysperma</i> (Torr. & A. Gray) H.H. Iltis	B,P	N
Convolvulaceae	<i>Ipomoea cordatotriloba</i> Dennst.		
	var. <i>torreyana</i> (A. Gray) D.F. Austin	B,E,P	N
Cucurbitaceae	<i>Cucurbita foetidissima</i> Kunth.	B,E	N
Cuscutaceae	<i>Cuscuta indecora</i> Choisy		
	var. <i>indecora</i>	CA,CO	N
Euphorbiaceae	<i>Chamaesyce nutans</i> (Lag.) Small	B,E	N
	<i>Cnidoscolus texanus</i> (Müll. Arg.) Small	CA,E	N
	<i>Croton glandulosus</i> L.		
	var. <i>lindheimeri</i> Müll. Arg.	E,P	N

Table 1. Cont.

Family	Species	Bordering Counties	N/I
Fabaceae	<i>Chamaecrista fasciculata</i> (Michx.) Greene	E,P	N
	<i>Dalea enneandra</i> Nutt.	B,CA,E,P,SH	N
	<i>Desmanthus illinoënsis</i> (Michx.) MacMill. ex B.L. Rob & Fernald	B,CO	N
	<i>Indigofera miniata</i> Ortega var. <i>miniata</i>	CO,E,P	N
	<i>Medicago minima</i> (L.) L.	B,P	I
	<i>Neptunia lutea</i> (Leavenw.) Benth.	B,P	N
	<i>Prosopis glandulosa</i> Torr.	B,CO,SH	N
Fumariaceae	<i>Corydalis aurea</i> Willd. subsp. <i>occidentalis</i> (Engelm. ex A. Gray) G.B. Ownbey	B,CA,CO,SH	N
Gentianaceae	<i>Eustoma russellianum</i> (Hook.) G. Don	B,CA,CO,E,P	N
Geraniaceae	<i>Erodium cicutarium</i> (L.) L'Her. ex Aiton	B,CA,CO,E,SH	I
Hyacinthaceae	<i>Muscari neglectum</i> Guss. ex Ten.	C	I
Hydrophyllaceae	<i>Phacelia congesta</i> Hook.	B,P	N
Iridaceae	<i>Nemastylis geminiflora</i> Nutt.	B	N
Juglandaceae	<i>Carya illinoensis</i> (Wangenh.) K. Koch	B	N
Lamiaceae	<i>Monarda punctata</i> L. var. <i>intermedia</i> (E.M. McClint. & Epling) Waterf.	B,CA,CO	N
Malvaceae	<i>Rhynchosida physocalyx</i> (A. Gray) Fryxell.	B,P,ST	N
	<i>Sphaeralcea angustifolia</i> (Cav.) G. Don var. <i>angustifolia</i>	B	N
Meliaceae	<i>Melia azedarach</i> L.	B,E	I
Nelumbonaceae	<i>Nelumbo lutea</i> (Willd.) Pers.	E	N
Nyctaginaceae	<i>Boerhavia diffusa</i> L.	P	N
Onagraceae	<i>Gaura brachycarpa</i> Small	B	N
	<i>Gaura sinuata</i> Nutt. ex Ser.	B,CO,E,SH	N
	<i>Ludwigia peploides</i> (Kunth) P.H. Raven	CA	N

Table 1. Cont.

Family	Species	Bordering Counties	N/I
	<i>Oenothera laciniata</i> Hill	CA,CO,E,P	N
Papaveraceae	<i>Argemone albiflora</i> Hornem. subsp. <i>texana</i> G.B. Ownbey	B	N
Pedaliaceae	<i>Proboscidea louisianica</i> (Mill.) Thell.	B,E,ST	N
Phytolaccaceae	<i>Rivina humilis</i> L.	E	N
Plantaginaceae	<i>Plantago rhodosperma</i> Decne.	B,CA,CO,E,SH	N
Poaceae	<i>Bothriochloa barbinodis</i> (Lag.) Herter var. <i>perforata</i> (Trin. ex E. Fourn.) Gould	B,E	N
	<i>Bothriochloa ischaemum</i> (L.) Keng var. <i>songarica</i> (Rupr. ex Fisch & C.A. Mey.) Celerier & Harlan	B	I
	<i>Bromus catharticus</i> Vahl	B,CO,E,SH	I
	<i>Erioneuron pilosum</i> (Buckley) Nash	B,CA,CO,SH,ST	N
	<i>Nassella leucotricha</i> (Trin. & Rupr.) R. Pohl	B,CA,P	N
	<i>Vulpia octoflora</i> (Walter) Rydb. var. <i>octoflora</i>	B,E	N
Polemoniaceae	<i>Ipomopsis rubra</i> (L.) Wherry	B,CA,CO,E,P,SH,ST	N
Rosaceae	<i>Prunus angustifolia</i> Marshall	B,CO,E,SH	N
	<i>Prunus mexicana</i> S. Watson	CO,E	N
Rubiaceae	<i>Cephalanthus occidentalis</i> L	B,E	N
Scrophulariaceae	<i>Castilleja indivisa</i> Engelm.	CA	N
	<i>Nuttallanthus texanus</i> (Scheele) D.A. Sutton	B,CA,CO,P	N
Verbenaceae	<i>Verbena bracteata</i> Lag. & Rodr.	E	N
Violaceae	<i>Viola bicolor</i> Pursh	E	N
Viscaceae	<i>Phoradendron tomentosum</i> (DC.) Engelm. ex A. Gray	B,CA,CO,SH	N
Zygophyllaceae	<i>Tribulus terrestris</i> L.	B,E	I

this species was in disturbed areas of the ranch. *Argemone albiflora* subsp. *texana* is known from weedy areas in rocky or sandy soils from east Texas, west to the Grand Prairie, and probably was introduced into the Rolling Plains (Diggs et al. 1999). It was collected from clay soils along the Leon River bottom on the ranch. *Bothriocloa ischaemum* var. *songarica* is native to Asia and found in calcareous soils from roadsides and fields throughout Texas and is a pernicious weed crowding out native species (Diggs et al. 1999). It was collected from rocky slopes on the ranch.

Two additional weedy species were previously reported from only a single county in the southwestern Cross Timbers (Table 1). *Sibara virginica* is known from wet thickets, ditches, and disturbed areas in southeast and east Texas to the Edwards Plateau and the Rolling Plains (Diggs et al. 1999). Collections of this species were from disturbed areas of the ranch and previously it had been collected only from Callahan County (Turner et al. 2003a). *Verbena bracteata* is known from disturbed areas and is widespread in Texas (Diggs et al. 1999). It was collected from grassland areas of the ranch and previously had only been reported only from Erath County (Turner et al. 2003a).

Five non-weedy species had been reported from only Brown County in the southwestern Cross Timbers (Turner et al. 2003a; 2003b). *Nemastylis geminiflora* is known from prairies or open oak woods in southeast and east Texas, west to the Rolling Plains and Edwards Plateau (Diggs et al. 1999). Collections of this species were from grassland areas of the ranch. *Carya illinoensis* is known from stream bottoms or slopes mainly in the eastern half of Texas and becoming scattered westward (Diggs et al. 1999). Collections of this species were from the Leon River bottomlands of the ranch. *Cooperia drummondii* is known from prairies and roadsides, often on thin soils covering limestone in southeastern and eastern Texas west to the West Cross Timbers and Edwards Plateau (Diggs et al. 1999). It was collected from a roadside on the ranch. *Sphaeralcea angustifolia* subsp. *cuspidata* is known from sandy or rocky soils

mainly in the western half of Texas (Diggs et al. 1999). Collections of this species were from disturbed areas of the ranch. *Gaura brachycarpa* is known from sandy open areas from the Post Oak Savannah west to the West Cross Timbers and south to the South Texas Plains (Diggs et al. 1999). Collections of this species were from grassland areas of the ranch.

Three non-weedy species had been reported from only Erath County in the southwestern Cross Timbers (Turner et al. 2003a; 2003b). *Nelumbo lutea* is known from lakes and ponds in southeastern and eastern Texas, west to the West Cross Timbers and Edwards Plateau (Diggs et al. 1999). Collections of this species were from ponds and lakes on the ranch. *Rivina humilis* is known from stream bottom woods and thickets on limestone soils throughout much of Texas (Diggs et al. 1999). It was collected along the Leon River on the ranch. *Viola bicolor* is known from eastern Texas west to the Rolling Plains and the Edwards Plateau (Diggs et al. 1999). It was collected in sandy grasslands on the ranch.

Four non-weedy species had previously been reported from only one county in the southwestern Cross Timbers (Turner et al. 2003a; 2003b). *Muscari neglectum* is widely cultivated and escapes becoming naturalized in fields and roadsides in north central, central, and east Texas (Diggs et al. 1999). Collections of this species were from disturbed areas of the ranch and previously it had been reported from only Comanche County in the southwestern Cross Timbers (Turner et al. 2003b). *Boerhavia diffusa* is known from rocky, gravelly, or sandy ground and is widespread in Texas (Diggs et al. 1999). It was collected in clay-soiled bottomlands along the Leon River on the ranch and previously had been reported only from Palo Pinto County in the southwestern Cross Timbers (Turner et al. 2003a). *Castilleja indivisa* is known from sandy or occasionally silty open woods, prairies, and disturbed areas from southeastern and east Texas, west to the East Cross Timbers but has been widely seeded by the Texas Highway Department (Diggs et al. 1999). It was collected in grasslands as well as gravelly to rocky

slopes on the ranch and it had previously been reported only from Callahan County (Turner et al. 2003a). Also, *Ludwigia peploides*, previously reported from only Callahan County (Turner et al. 2003a), was collected from ponds and lakes on the ranch. It is known from wet areas from southeast and eastern Texas to the West Cross Timbers and Edwards Plateau (Diggs et al. 1999).

Two species endemic to Texas are reported for the first time in Eastland County. *Senecio ampullaceus* is found in sandy open woods, fields, and on roadsides (Diggs et al. 1999). It was collected in sandy grasslands on the ranch and previously it had only been reported from Callahan and Comanche counties (Turner et al. 2003a). *Monarda punctata* L. var. *intermedia* is the most common variety of *M. punctata* in north central Texas and is known from there, west to the Rolling Plains and the eastern Edwards Plateau (Diggs et al. 1999). It was collected from a roadside on the ranch and previously it had only been reported from Brown, Callahan, and Erath counties in the southwestern Cross Timbers (Turner et al. 2003a).

Seven species represent major range extensions for plant species in Texas. While most of the flora collected in this investigation was native (91%), 57% of the major range extensions are introduced weeds. New distribution records for these taxa are discussed individually by family.

FAMILY ACANTHACEAE

Ruellia humilis Nutt. is a native forb found in prairies and open woods in southeastern and east Texas, west to the Panhandle and the Edwards Plateau (Diggs et al. 1999) but is considered rare in the western three-fourths of the state (Correll & Johnston 1970). It was collected in grasslands on the ranch. Previously, it had not been collected in the southwestern Cross Timbers and the closest collection was from Hill County (Turner et al. 2003a) approximately 120 km east of Eastland County.

FAMILY BORAGINACEAE

Lithospermum arvensis L. is an introduced species from Europe and known from ditch banks, roadsides, and other disturbed sites from southeastern and eastern Texas, west to the West Cross Timbers and Edwards Plateau (Diggs et al. 1999). It was found in disturbed areas of the ranch. The closest reported locality to the West Cross Timbers is San Saba County to the south and Tarrant County to the northeast (Turner et al. 2003a). This collection from Eastland County is about 120 km from each of these localities.

FAMILY CARYOPHYLLACEAE

Stellaria media (L.) Vill. is an introduced species from Europe and is a widespread weed of stream bottoms, lawns, and disturbed sites nearly throughout Texas. It was collected in disturbed areas of the ranch. The closest reported localities (Turner et al. 2003a) to the West Cross Timbers are Burnet County approximately 160 km south and Parker County approximately 80 km northeast of the region.

FAMILY FABACEAE

Vicia sativa L. is an introduced species from Europe and the Mediterranean region and is frequently cultivated and escapes to roadside and weedy areas in southeastern and eastern Texas, west to the East Cross Timbers (Diggs et al. 1999). Collection of this species was from grassland areas of the ranch. Since Tarrant County is the closest reported locality to the northeast and Hill County to the east (Turner et al. 2003a), this extends the range of this species about 120 km south and west into the West Cross Timbers.

FAMILY IRIDACEAE

Sisyrinchium minus Engelm. & A. Gray is native and known from sandy soils mainly in southeastern and central Texas (Diggs et al. 1999). It was collected in grasslands on the ranch and

previously was known from Tarrant County to the north and San Saba County to the south (Turner et al. 2003b). Collection of this species from Eastland County is about 120 km from each of these localities.

FAMILY PORTULACACEAE

Portulaca oleracea L. is a cosmopolitan weed that is probably introduced from the Old World and is known from dry lake beds and disturbed areas nearly throughout Texas (Diggs et al. 1999). It was collected from disturbed areas of the ranch and the closest localities previously reported (Turner et al. 2003a) from the West Cross Timbers are from Parker County, about 40 km northeast of Eastland County.

FAMILY SOLANACEAE

Physalis longifolia Nutt. is a native forb known from open woods and prairies throughout most of Texas (Diggs et al. 1999). It was collected from disturbed areas on the ranch. The closest reported locality to the West Cross Timbers is Tarrant County (Turner et al. 2003a), about 120 km to the northeast.

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THE VASCULAR FLORA OF AN OLD-GROWTH COLUMBIA BOTTOMLAND FOREST REMNANT, BRAZORIA COUNTY, TEXAS

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Abstract.—A floristic survey of the Dance Bayou Unit, a 263 ha Columbia Bottomland forest stand within the San Bernard National Wildlife Refuge, was conducted in order to provide a checklist of the vascular flora of an old-growth Columbia Bottomland Forest remnant. Collecting trips were made to the refuge unit from November 2001 through September 2004, and resulted in a catalog of 356 species of vascular plants representing 83 families and 237 genera. The four largest families are Poaceae (54 sp.), Asteraceae (35 sp.), Cyperaceae (32 sp.), and Fabaceae (20 sp.). Non native species accounted for 15% (55 sp) of the total flora. Notes on physical and chemical soil properties, as well as forest ecological and physiognomic features are provided.

The bottomland hardwood forests adjacent to the Brazos, Colorado, and San Bernard rivers of the upper Texas coast are known regionally as the Columbia Bottomlands (Fig. 1). The Columbia Bottomlands extend from the Texas coast, approximately 150 km inland, and includes parts of seven counties. It's estimated that the Columbia Bottomlands (known alternatively as Austin's Woods), comprised over 283,000 ha at the beginning of the last century (U. S. Fish and Wildlife Service 1997). Today, the forest covers about 71,632 ha, and the remaining stands are highly fragmented and continuously lost or degraded through residential and commercial development, overgrazing, timbering, and infestation of non native plants (U. S. Fish and Wildlife Service 1997; Barrow & Renne 2001; Barrow et al. 2003). Recent studies utilizing Geographic Information Systems suggested a loss of approximately 17% between 1979 and 1995 (Webb 1997).

The recognition of the importance of bottomland forests adjacent to the Gulf of Mexico as stopover and staging habitat for Nearctic-

Neotropical migrant landbirds has emphasized the dire need for the conservation of a substantial area of the remaining tracts, and a deeper understanding of the ecological processes of these forests (Barrow et al. 2003). Millions of Nearctic-Neotropical migrant landbirds move through the coastal forests of the Gulf of Mexico during annual migration (Barrow et al. 2003). The Columbia Bottomlands provides the only expanse of forest adjacent to the Gulf of Mexico in Texas. An estimated 29 million Nearctic-Neotropical migrant landbirds represented by 65-70 species migrate through the Columbia Bottomlands annually (Barrow pers. comm.; U. S. Fish and Wildlife Service 1997).

Hamilton et al. (2005) included the Dance Bayou Unit in an enumeration of extant old growth bottomland forests of the southeast United States. The Dance Bayou Unit is a 263 ha Columbia Bottomland forest stand within the San Bernard National Wildlife Refuge (SBNWR), and administered by the U. S. Fish and Wildlife Service (USFWS). The Dance Bayou Unit does not lie within the boundaries of the SBNWR, but is a satellite unit located approximately 35 km NW of the refuge headquarters, near the town of West Columbia (Fig. 1). As suggested by Runkle (1982) for other old-growth remnants, the Dance Bayou Unit is without obvious large-scale human disturbance such as timbering, thinning, selective cutting, burning, or overgrazing, and likely represents climax vegetation. Some minor clearing has occurred to accommodate hunting, an abandoned county dirt-road, and a pipeline right-of-way, but the overall area disturbed by these activities was small. Other old-growth indicators include a diverse and uneven aged tree community, abundant standing snags and fallen trees, abundant large vines, tree fall gaps, and numerous large, uniquely shaped or super-emergent specimen trees (Hamilton et al. 2004). Old growth bottomland forest, like the Dance Bayou Unit, provides structural complexity known to be important for sustaining an abundance of forest dwelling birds (Hamilton et al. 2004; Barrow et al. 2000).

The significant natural resource and conservation priority that the Columbia Bottomlands represent and the apparent accelerating

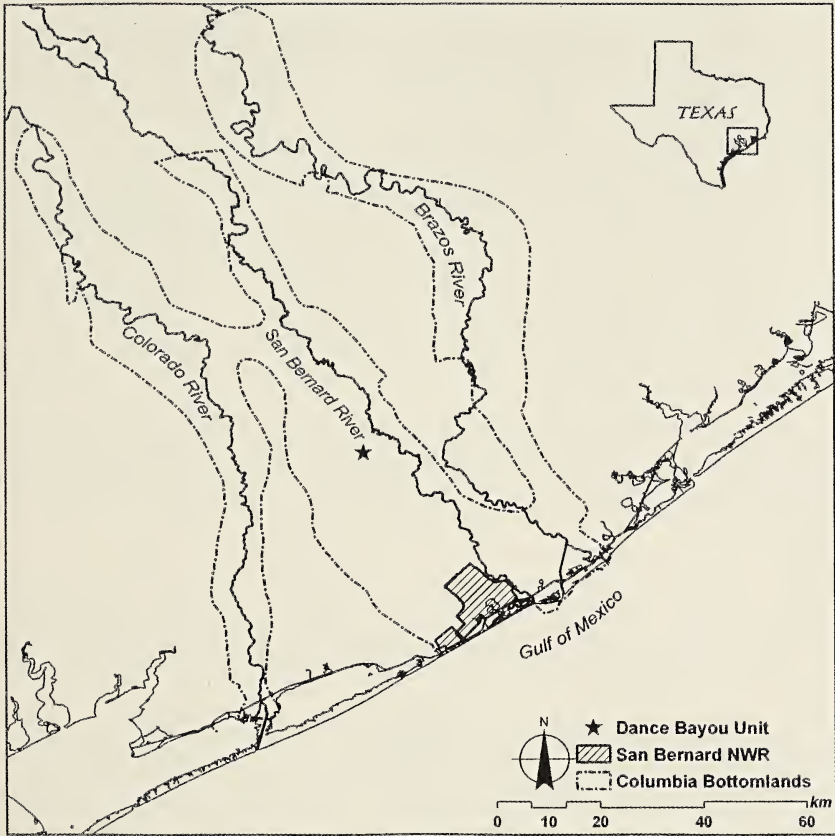


Figure 1. Map showing location of the Dance Bayou Unit, location and boundaries of the San Bernard National Wildlife Refuge, and location and boundaries of the Columbia Bottomlands.

loss of the remaining areas gave rise to the study reported here. The purpose of this study was to provide a detailed account of the vascular flora and details of soil characteristics of an old-growth Columbia Bottomland forest in order to: (1) characterize its floristic uniqueness; (2) facilitate future quantitative and experimental studies of Columbia Bottomland forest community dynamics; (3) provide a benchmark for Columbia Bottomland forest management and restoration; and (4) provide a plant species list to supplement additional faunal studies at the Dance Bayou unit.

STUDY AREA

The Columbia Bottomlands lie within the Coastal Plain Province at the northern limit of the subtropical vegetation zone (Fenneman 1928; Good 1953). The forests of the Columbia Bottomlands formed on Holocene fluvial deposits laid down by the major tributaries that traverse the region (Crenwelge et al. 1981; Geologic Atlas of Texas 1968). Three rivers transect the Columbia Bottomlands, the Brazos, Colorado, and San Bernard, all flowing generally southeasterly to the Gulf of Mexico (Fig. 1). The regional climate is moist subhumid mesothermal characterized by long hot summers and mild winters (Thorntwaite 1948). Average annual rainfall is 132 cm, with 60% occurring from April through September (Crenwelge et al. 1981). The average daily summer temperature is 27°C, and average daily winter temperature is 13°C (Crenwelge et al. 1981).

Soils mapped in the Dance Bayou Unit are Pledger clay and Asa silty clay loam, rarely flooded (Crenwelge et al. 1981). The Pledger and Asa soils formed in recent reddish, brownish, or yellowish clayey and micaceous loamy sediments which are characteristic of the Colorado River deposits in the Texas Gulf Coast Prairie Major Land Resource Area (Soil Survey Staff 1981; Miller 1986). The entry gate to the Dance Bayou Unit is located at 29° 7' 7.73"N, 95° 47' 10.12"W in SW Brazoria County, Texas. The unit is bounded on all sides by private property, and traversed by Dance Bayou, a small distributary of the San Bernard River for which the unit is named.

MATERIALS AND METHODS

Topographical maps and color infrared aerial photos were examined in order to locate different habitats and plan fieldwork. Sporadic collecting trips were made to the refuge unit from November 2001 through September 2004. A complete set of voucher specimens were deposited to the Spring Branch Science Center Herbarium (SBSC) with some duplicates deposited to the

Table 1. Taxonomic summary of the vascular plants of the Dance Bayou Unit; San Bernard National Wildlife Refuge.

	Families	Genera	Species		
			Native	Non Native	Total
Polypodiopsida (ferns)	4	4	4	0	4
Pinopsida (gymnosperms)	1	1	1	0	1
Liliopsida (monocots)	14	50	90	22	112
Magnoliopsida (dicots)	64	182	206	33	239
Totals	83	237	301	55	356

Botanical Research Institute of Texas (BRIT) and the University of Western Ontario (UWO); herbarium acronyms follow Holmgren et al. 1990). When available, duplicates were deposited to other herbaria. Plant identifications were made using various regional manuals including Correll & Johnston (1970), Gould (1975), Godfrey (1988), Isely (1990), and Smith (1994). Some difficult specimens were presented to various experts for identification.

Field studies including soil profile descriptions of Pledger clay and Asa silty clay loam soils at the Dance Bayou Unit have been ongoing since August 1998. Soils mapped as Asa at the Dance Bayou Unit were within the Asa series range of characteristics and were not sampled. The Asa series type location is on a similar landscape, and physical and chemical analysis was obtained from the series type location characterization data. However, since no data was available for Pledger clay, physical and chemical analyses were conducted at various landscape positions and the results are included herewith.

RESULTS

Collecting trips yielded 356 species of vascular plants representing 83 families and 237 genera (Table 1). The four families containing the most species are Poaceae (54 sp.), Asteraceae (35 sp.), Cyperaceae (32 sp.), and Fabaceae (20 sp.). The largest

genus is *Carex* with 19 species. One species, *Alternanthera sessilis* (sessile joyweed), is listed by the U.S. Department of Agriculture as a noxious weed. Non native species accounted for 15% (55 sp.) of the total species. No Federally-listed threatened or endangered plant species were found.

ANNOTATED CHECKLIST OF VASCULAR PLANT SPECIES OF THE DANCE BAYOU UNIT

Plant names are arranged by class, and then listed alphabetically within class by family, genus, and species using the classification system in Jones et al. (1997). Familiar synonymy for select species is provided in brackets. Each species is followed by a common name gleaned from regional manuals, and collection number for the first author, or other author if indicated. Non native species, based on review of Hatch et al. (1990) and Correll & Johnston (1970) are indicated by an asterisk (*).

POLYPODIOPSIDA (Ferns and Fern Allies)

ASPLENIACEAE

Asplenium platyneuron (L.) Britt., Sterns, & Poggenb., ebony spleenwort, 1854.

OPHIOGLOSSACEAE

Botrychium biternatum (Savigny) Underw., southern grape fern, 1906.

POLYPODIACEAE

Polypodium polypodioides (L.) Watt, resurrection fern, 1806.

THELYPTERIDACEAE

Thelypteris kunthii (Desv.) C. V. Morton, wide-spread maiden fern, 1761.

PINOPSIDA (Gymnosperms)

CUPRESSACEAE

Juniperus virginiana L. var. *virginiana*, eastern red-cedar, sight record.

LILIOPSIDA (Monocots)

ALISMATACEAE

- Echinodorus beteroi* (Spreng.) Fassett, beaked burhead, 2090
Echinodorus cordifolius (L.) Griseb. subsp. *fluitans* (Fassett) R.
R. Haynes & L. B. Holm-Niels., heart-leaf burhead, 2075
Sagittaria graminea Michx. subsp. *graminea*, grass-leaf
arrowhead, 1891.
Sagittaria platyphylla (Engelm.) J. G. Sm., delta arrowhead,
1892.

ALLIACEAE

- Allium canadense* L., Canada meadow onion, 1805.

ARACEAE

- Arisaema dracontium* (L.) Schott, green dragon, 1857.

ARECACEAE

- Sabal minor* (Jacq.) Pers., dwarf palmetto, 2177.

BROMELIACEAE

- Tillandsia recurvata* (L.) L., small ball moss, 1900.
Tillandsia usneoides (L.) L., Spanish moss, 2934.

COMMELINACEAE

- Commelina diffusa* N. L. Burnman, spreading day-flower, 2092.

CYPERACEAE

- Carex basiantha* Steud., basal-fruit caric-sedge, 1844.
Carex blanda Dewey, charming caric-sedge, 1890.
Carex bulbostylis Mack., globose caric-sedge, 1845.
Carex caroliniana Schwein., Carolina caric-sedge, 2458.
Carex cherokeënsis Schwein., Cherokee caric-sedge, 1877.
Carex corrugata Fernald, wrinkle-fruit caric-sedge, 1843.
Carex crus-corvi Shuttlew.ex Kunze, crowfoot caric-sedge,
1894.
Carex flaccosperma Dewey, flaccid-fruit caric-sedge, 1856.
Carex frankii Kunth, Frank's caric-sedge, 2073.
Carex hyalinolepis Steud., hyaline-scale caric-sedge, 1947.
Carex leavenworthii Dewey, Leavenworth's caric-sedge, 1849.

- Carex louisianica* L. H. Bailey, Louisiana caric-sedge, 2025.
Carex lupuliformis Sartwell ex Dewey, hop-like caric-sedge, 2129.
Carex lupulina Muhl. ex Willd., hop caric-sedge, 2032.
Carex oxylepis Torr. & Hook. var. *oxylepis*, sharp-scale caric-sedge, 1842.
Carex retroflexa Muhl. ex Willd., reflexed-fruit caric-sedge, 1886.
Carex tetrastachya Scheele, four-angled caric-sedge, 2115.
Carex texensis (Torr. ex L. H. Bailey) L. H. Bailey, Texas caric-sedge, 1847.
Carex tribuloides Wahlenb. var. *sangamonensis* Clokey, Sangamon caltrop caric-sedge, 2074.
Cyperus croceus Vahl, Baldwin's flat-sedge, 2193.
* *Cyperus entrerianus* Böeck., deeprooted sedge, 2095.
Cyperus esculentus L. var. *esculentus*, yellow nutgrass, 2334.
Cyperus ochraceus Vahl, pond flat-sedge, 2187.
Cyperus pseudovegetus Steud. var. *pseudovegetus*, marsh flat-sedge, 2114.
* *Cyperus rotundus* L., purple nutgrass, 2927.
Cyperus thyrsoflorus Jungh., coastal plain flat-sedge, 1945.
Cyperus virens Michx. var. *virens*, green flat-sedge, 2030.
Eleocharis acicularis (L.) Roem. & Schult. var. *acicularis*, needle spikerush, 2087.
Eleocharis montevidensis Kunth, sand spikerush, 2081.
Eleocharis palustris (L.) Roem. & Schult., marsh spikerush, 2353.
Kyllinga brevifolia Rottb., short-leaf spike-sedge, 2467.
Rhynchospora corniculata (Lam.) A. Gray, horned beakrush, 2088.
Scleria oligantha Michx., small-head nutrush, 1880.

IRIDACEAE

- Herbertia lahue* (J. Molina) P. Goldblatt, South Texas herbertia, 1887. endemic
Sisyrinchium langloisii Greene, dotted blue-eyed grass, 2465.

JUNCACEAE

- Juncus acuminatus* Michx., taper-tip rush, 2450.
Juncus effusus L., soft rush, 2463.
Juncus marginatus Rostk., grass-leaf rush, 2033.
Juncus tenuis Willd. var. *tenuis*, slender rush, 2082.

LEMNACEAE

- Lemna obscura* (Austin) Daubs, little duckweed, 2964.
Spirodela polyrhiza (L.) Schleid., duckmeat, 2965.

LILIACEAE

- Nothoscordum bivalve* (L.) Britt., crow-poison, 1768.

ORCHIDACEAE

- Spiranthes ovalis* Lindl. var. *ovalis*, nodding ladies'-tresses,
Liggio s.n.
Spiranthes cernua (L.) Rich., oval ladies'-tresses, 2389.

POACEAE

- Andropogon glomeratus* (Walter) Britt., Sterns, & Poggenb. var.
pumilus Vasey, bushy bluestem, 2356.
Andropogon virginicus L. var. *virginicus*, broom-sedge blue-
stem, 2397.
Arundinaria gigantea (Walter) Muhl. subsp. *gigantea*, giant
cane, 2632.
* *Bothriochloa ischaemum* (L.) Keng, King Ranch bluestem,
2215.
Bothriochloa longipaniculata (F. Gould) K. Allred & F. Gould,
long-spike silver blue-stem, 2237.
* *Briza minor* L., little quaking-grass, 1911.
* *Bromus catharticus* Vahl, rescue grass, 1869.
* *Cenchrus spinifex* Cav., coastal sand-bur, 2335.
Chasmanthium latifolium (Michx.) H. O. Yates, broad-leaf
wodoats, 2223.
Chasmanthium laxum (L.) H. O. Yates var. *sessiliflorum* (Poirot)
Wipff & S. D. Jones, hairy-collar wodoats, 2135.
* *Chloris canterae* Arechav. var. *canterae*, Paraguay windmill-
grass, 2573.
* *Cynodon dactylon* (L.) Pers., Bermuda-grass, 2209.

- * *Dactyloctenium aegyptium* (L.) P. Beauv., Egyptian crow's-foot-grass, s.n.
- Digitaria ciliaris* (Retz.) Köeler var. *ciliaris*, fringed crab-grass, 2176.
- * *Echinochloa colona* (L.) Link, jungle rice, 2333.
- * *Echinochloa crus-galli* (L.) P. Beauv. var. *crus-galli*, large barn-yard-grass, 2100.
- * *Eleusine indica* (L.) Gaertn. subsp. *indica*, goosefoot-grass, 2336.
- Elymus virginicus* L. var. *virginicus*, Virginia wildrye, 1949.
- Hordeum pusillum* Nutt., little barley, 1870.
- Leersia lenticularis* Michx., catchfly grass, 2105.
- Leersia monandra* Sw., bunch cut-grass, 2396.
- Leersia virginica* Willd., Virginia cut-grass, 2020.
- Leptochloa panicea* (Retz.) Ohwi subsp. *brachiata* (Steud.) N. Snow, branching sprangletop, 2235.
- * *Lolium arundinaceum* (Schreb.) Darbysh., cane-like rye-grass, 2700.
- * *Lolium perenne* L., perennial rye-grass, 1776.
- Melica mutica* Walter, two-flower melic-grass, 1767.
- Muhlenbergia schreberi* J. F. Gmel., nimblewill, 2021.
- Nassella leucotricha* (Trin. & Rupr.) R. W. Pohl, Texas winter grass, 2466.
- * *Oplismenus hirtellus* (L.) P. Beauv. subsp. *setarius* (Lam.) Mez, basket-grass, 2226.
- Panicum anceps* Michx. var. *anceps*, beaked panic-grass, 2131.
- Panicum commutatum* Schult. var. *commutatum*, variable panic-grass, 1841.
- Panicum gymnocarpon* Elliott, swamp panic-grass, 2130.
- Panicum laxiflorum* Lam., open-flower rosette-grass, 2420.
- Panicum rigidulum* Nees var. *rigidulum*, red-top panic-grass, 2258.
- Paspalum conjugatum* P. J. Bergius, *lividum* Trin.], sour paspalum, 2221.
- Paspalum denticulatum* Trin. [Sy = *Paspalum long-tom*, 2197.
- * *Paspalum dilatatum* Poiret, dallis-grass, 2014.

- Paspalum langei* (E. Fourn.) Nash, woodland paspalum, 2222.
- * *Paspalum notatum* Flüggé, bahia grass, 2113.
- Paspalum repens* P. J. Bergius var. *fluitans* (Elliott) Wipff & S. D. Jones, creeping water paspalum, 2188.
- * *Paspalum urvillei* Steud., vasey-grass, 2152.
- Phalaris angusta* Nees ex Trin., timothy canary-grass, 1897.
- Phalaris caroliniana* Walter, Carolina canary-grass, 1895.
- Poa annua* L., annual blue-grass, 2399.
- Poa autumnalis* Muhl. ex Elliott, autumn blue-grass, 1840.
- * *Setaria pumila* (Poiret) Roem. & Schult., bristle-grass, s.n.
- * *Sorghum halepense* (L.) Pers., Johnson-grass, 2098.
- Sphenopholis obtusata* (Michx.) Scribn., prairie wedge-grass, 2462.
- Sporobolus compositus* (Poiret) Merr. var. *compositus*, drop-seed, 2638.
- Sporobolus indicus* (L.) R. Br. var. *indicus*, smut grass, 2195.
- * *Stenotaphrum secundatum* (Walter) Kuntze, St. Augustine grass, 2210.
- Tridens flavus* (L.) Hitch. var. *flavus*, purple-top tridens, 2351.
- Urochloa platyphylla* (Munro ex Wright) R. D. Webster, broad-leaf liver-seed grass, 2574.
- * *Urochloa reptans* (L.) Stapf, creeping liver-seed grass, 2245.
- Zizaniopsis miliacea* (Michx.) Döll & Asch., southern wild rice, 2461.

SMILACACEAE

- Smilax bona-nox* L., saw greenbrier, 2886.
- Smilax rotundifolia* L., common greenbrier, 1875.
- Smilax smallii* Morong, Small's greenbrier, 2024.

MAGNOLIOPSIDA (Dicots)

ACANTHACEAE

- Dicliptera brachiata* (Pursh) K. Spreng., branched fold-wing, 3055.
- Hygrophila lacustris* (Cham. & Schltdl.) Nees, gulf swampweed, 2076.

Justicia ovata (Walter) Lindau var. *lanceolata* (Chapm.) R. W. Long, lance-leaf water-willow, 2028.

Ruellia nudiflora (Engelm. ex A. Gray) Urban var. *nudiflora*, wild-petunia, 2224.

Ruellia strepens L., smooth wild-petunia, 2012.

ACERACEAE

Acer negundo L., box-elder, 1915.

AMARANTHACEAE

* *Alternanthera sessilis* (L.) R. Br. ex DC., sessile joyweed, 2106.
Federal Noxious Weed

* *Amaranthus viridis* L., tropical green pigweed, 2928
Amaranthus rudis J. D. Sauer, water-hemp, 2243.

ANACARDIACEAE

Toxicodendron radicans (L.) Kuntze, poison-ivy, 2136.

APIACEAE

* *Chaerophyllum tainturieri* Hook., chervil, 2018.

Cyclospermum leptophyllum (Pers.) Sprague ex Britton & P. Wilson, slim-lobe celery, 2404.

Cynoscium digitatum DC., finger dogshade, 1946.

Eryngium hookeri Walp., Hooker's eryngo, 2172.

Hydrocotyle verticillata Thunb., water-pennywort, 1876.

Sanicula canadensis L., Canadian sanicle, 2027.

Sanicula odorata (Raf.) Pryer & Phillippe, black snakeroot, 1861.

* *Torilis nodosa* (L.) Gaertn., knotted hedge-parsley, 1909.
Trepocarpus aethusae Nutt. ex DC., white nymph, 2019.

AQUIFOLIACEAE

Ilex decidua Walter, possumhaw, 2102.

Ilex opaca Sol. var. *opaca*, American holly, 2401.

Ilex vomitoria Aiton, yaupon holly, 2978.

ASCLEPIADACEAE

Asclepias perennis Walter, aquatic milkweed, 2031.

Asclepias viridis Walter, antelope-horn milkweed, 2139.

Matelea gonocarpus (Walter) Shinnars, angle-pod milkvine, 2526.

ASTERACEAE

Iva annua L. var. *annua*, sea-coast sumpweed, 2359.

Acmella oppositifolia (Lam.) R. K. Jansen var. *repens* (Walter) R. K. Jansen, opposite-leaf creeping spot-flower, 2083.

Ambrosia psilostachya DC., western ragweed, 2634.

Ambrosia trifida L., giant ragweed, 2332.

Baccharis halimifolia L., eastern baccharis, 2338.

Bidens bipinnata L. var. *bitermatoides* Sherff, six spanish needles, 2216.

Calyptocarpus vialis Less., straggler daisy, 2122.

Centaurea americana Nutt., basketflower, 2173.

Chlorocantha spinosa (Benth.) G. Nesom var. *spinosa*, spiny aster, 2358.

Conoclinium coelestinum (L.) DC., blue mistflower, 2185.

Coreopsis tinctoria Nutt., tickseed, 2094.

Eclipta prostrata (L.) L., yerba de tago, 2103.

Elephantopus carolinianus Raeusch., Carolina elephant's-foot, 2259.

Erigeron geiseri Shinnars var. *geiseri*, Geiser's fleabane, *Adams & Hannah s.n.* endemic

Erigeron philadelphicus L., Philadelphia fleabane, 1838.

Eupatorium serotinum Michx., saw-leaf thoroughwort, 2387.

Fleischmannia incarnata (Walter) R.M. King & H. Rob., Fleischmann's thoroughwort, 2352.

* *Hypochaeris microcephala* (Sch. Bip.) Cabrera var. *albiflora* (Kuntze) Cabrera, white-flowered cat's-ear, 2029.

Krigia cespitosa (Raf.) K. L. Chambers, dwarf-dandelion, 2470.

Lactuca floridana (L.) Gaertn. var. *floridana*, woodland lettuce, 2329.

Mikania scandens (L.) Willd., climbing hempweed, 2637.

Packera tampicana (DC.) C. Jeffrey, Tampico butterweed, 1871.

Parthenium hysterophorus L., false ragweed, 2120.

Pluchea camphorata (L.) DC., camphorweed, 2328.

Pyrrhopappus carolinianus (Walter) DC., Carolina false dandelion, 2208.

Pyrrhopappus pauciflorus (D. Don) DC., small-flowered false dandelion, 1773.

Ratibida columnifera (Nutt.) Wooton & Standl., Mexican-hat, 2017.

Rudbeckia hirta L., brown-eyed susan, 2194.

Smallanthus uvedalia (L.) Mack. ex Small, bear's-foot leafcup, 3156.

Solidago canadensis L. var. *scabra* (Muhl. ex Willd.) Torr. & A. Gray, rough-leaf Canadian goldenrod, 2235.

* *Sonchus oleraceus* L., common sowthistle, 2232.

Symphyotrichum dumosum (L.) G. Nesom, bushy aster, 2395. (duplicate at BRIT)

Symphyotrichum racemosum (Elliott) G. Nesom var. *subdumosum* (K. Wiegand) G. Nesom, bush raceme aster, 2388. (duplicate at BRIT)

Verbesina virginica L. var. *virginica*, Virginia frostweed, 2178.

Vernonia missurica Raf., Missouri ironweed, 2633.

* *Youngia japonica* (L.) DC., Japanese hawkweed, 1881.

BIGNONIACEAE

Campsis radicans (L.) B. Seemann ex E. Bureau, trumpet-creeper, 2116.

BORAGINACEAE

Heliotropium indicum L., Indian heliotrope, 2144.

Heliotropium procumbens Mill. var. *procumbens*, four-spike heliotrope, 2108.

Myosotis macrosperma Engelm., spring forget-me-not, 1839.

BRASSICACEAE

* *Cardamine debilis* D. Don, weak bittercress, 1779.

Lepidium virginicum L. var. *medium* (Greene) C.L. Hitchc., Virginia pepperwort, 1777.

Rorippa palustris (L.) Besser, yellowcress, 2091.

CAMPANULACEAE

Triodanis lamprosperma McVaugh, prairie venus' looking-glass, 2016.

CAPRIFOLIACEAE

* *Lonicera japonica* Thunb., Japanese honeysuckle, 1904.

Sambucus nigra L. var. *canadensis* (L.) B.L. Turner, common elderberry, 2132.

Symphoricarpos orbiculatus Moench, coralberry, 2180.

Viburnum dentatum L., southern toothed arrow-wood, 2089.

Viburnum rufidulum Raf., rusty blackhaw, 1905.

CARYOPHYLLACEAE

* *Cerastium glomeratum* Thuill., sticky mouse-ear chickweed, 1778.

Stellaria prostrata Baldwin ex Elliott, prostrate starwort, 2801.

CHENOPODIACEAE

* *Chenopodium berlandieri* Moq., Berlandier's goose-foot, 2192.

CONVOLVULACEAE

Dichondra carolinensis Michx., Carolina pony-foot, 1858.

Ipomoea cordatotriloba Dennst. var. *cordatotriloba*, tie-vine, 2119.

Ipomoea lacunosa L., white-star morning glory, 2257.

CORNACEAE

Cornus drummondii C. A. Mey., rough-leaf dogwood, 2013.

CRASSULACEAE

Penthorum sedoides L. subsp. *sedoides*, ditch stonecrop, 2527.

CUCURBITACEAE

Melothria pendula L. var. *pendula*, drooping melonette, 2217.

CUSCUTACEAE

Cuscuta pentagona Engelm., dodder, 2198.

EBENACEAE

Diospyros virginiana L., common persimmon, 2926.

EUPHORBIACEAE

Acalypha gracilens A. Gray, slender three-seeded mercury, 1759.

Acalypha rhomboidea Raf., rhombic-leaf three-seed mercury, 2142.

Caperonia palustris (L.) A. St.-Hil., marsh false-croton, 2143.

Chamaesyce nutans (Lag.) Small [Sy = *Euphorbia nutans* Lag.], eyebane sand-mat, 2156.

Chamaesyce serpens (Kunth) Small [Sy = *Euphorbia serpens* Kunth], matted sand-mat, 2212.

Croton capitatus Michx. var. *lindheimeri* (Engelm. & A. Gray) Müll. Arg., Lindheimer's hogwort croton, 2148.

Croton monanthogynus Michx., one-seed croton, 2339.

Euphorbia bicolor Engelm. & A. Gray, snow-on-the-prairie, 2171.

Euphorbia dentata Michx., toothed spurge, 2230.

Euphorbia spathulata Lam., warty spurge, 1863.

Phyllanthus pudens L. C. Wheeler, bird-seed leafflower, 2213.

* *Triadica sebifera* (L.) Small [Sy = *Sapium sebiferum* (L.) Roxb.], Chinese tallow-tree, 2096.

Tragia urticifolia Michx., nettle-leaf noseburn, 2078.

FABACEAE

* *Albizia julibrissin* Durazz., mimosa tree, sight record.

Amphicarpaea bracteata (L.) Fernald, American hogpeanut, 2331.

Desmanthus illinoënsis (Michx.) C. MacMillan ex Robinson & Fern., Illinois bundleflower, 2138.

Desmodium canescens (L.) DC., hoary ticktrefoil, 2151.

Desmodium glabellum (Michx.) DC., Dillenius' ticktrefoil, 2011.

Galactia volubilis (L.) Britt., twining milkpea, 2239.

Lathyrus pusillus Elliott, low pea-vine, 1865.

* *Medicago arabica* (L.) Huds., Arabian medick, 2454.

- * *Medicago lupulina* L., black medick, 1867.
- * *Medicago polymorpha* L., burclover, 1910.
- * *Melilotus indicus* (L.) All., annual sourclover, 1908.
- Mimosa strigillosa* Torr. & A. Gray, pink sensitivebrier, 2111.
- Neptunia pubescens* Benth., prairie neptunia, 2207.
- Rhynchosia minima* (L.) DC. var. *minima*, least snoutbean, 2140.
- Senna obtusifolia* (L.) H. S. Irwin & Barneby, coffeeweed senna, 2107.
- * *Senna occidentalis* (L.) Link, western senna, 3157
- Sesbania drummondii* (Rydb.) Cory, Drummond's rattlebush, 2225.
- * *Trifolium campestre* Schreb. var. *campestre*, hop clover, 1893.
- * *Trifolium repens* L. var. *repens*, white clover, 1769.
- * *Trifolium resupinatum* L., Persian clover, 1866.
- Vicia ludoviciana* Nutt., Leavenworth's Louisiana vetch, 1913.

FAGACEAE

- Quercus alba* L., white oak, 2887.
- Quercus nigra* L., water oak, 2159.
- Quercus shumardii* Buckley, Shumard oak, 1758.
- Quercus texana* Buckley, [Sy = *Q. nuttallii* E. Palmer], Nuttall's oak, 2086.
- Quercus virginiana* Mill. var. *virginiana*, live oak, 2158.

GENTIANACEAE

- Centaurium muhlenbergii* (Griseb.) W. Wight ex Piper, Muhlenberg's centaury, 2524.

GERANIACEAE

- Geranium carolinianum* L. var. *carolinianum*, Carolina crane's-bill, 1864.

HALORAGACEAE

- Proserpinaca palustris* L. var. *amblyogona* Fernald, marsh mermaidweed, 2955.

JUGLANDACEAE

- Carya aquatica* (F. Michx.) Nutt., water hickory, 2157.
- Carya illinoensis* (Wangenh.) K. Koch, sweet pecan, 2635.
- Juglans nigra* L., eastern black walnut, sight record.

LAMIACEAE

Lycopus virginicus L., Virginia water horehound, 2398.

Micromeria brownei (Sw.) Benth. var. *pilosiuscula* A. Gray,
Browne's savory, 2219.

Monarda citriodora Cerv. ex Lag., lemon beebalm, 2015.

Physostegia intermedia (Nutt.) Engelm. & A. Gray, obedient-
plant, 2449.

Prunella vulgaris L., selfheal, 2034.

Salvia lyrata L., lyre-leaf sage, 1860.

Scutellaria ovata Hill, egg-leaf skullcap, 2069.

Stachys crenata Raf., mouse-ear betony, 1874.

Teucrium canadense L. var. *canadense*, Canadian germander,
2184.

Teucrium cubense Jacq. var. *cubense*, costal germander, 2234.

LINACEAE

Linum berlandieri Hook., Berlandier's flax, 2471.

LOGANIACEAE

Spigelia texana (Torr. & A. Gray) A. DC., Texas pinkroot, 1944.
endemic

LYTHRACEAE

Lythrum alatum Pursh var. *lanceolatum* (Elliott) Rothr., lance-
leaf loosestrife, 2155.

MALVACEAE

Hibiscus moscheutos L. subsp. *lasiocarpus* (Cav.) O. Blanchard,
woolly crimson-eyed rosemallow, 2196.

Malvaviscus drummondii Torr. & A. Gray, Drummond's
waxmallow, 2153.

Modiola caroliniana (L.) G. Don, Carolina bristlymallow, 2889.

Sida rhombifolia L., rhombic-leaf fanpetals, 2218.

MELIACEAE

* *Melia azedarach* L., Chinaberry tree, 2455.

MENISPERMACEAE

Cocculus carolinus (L.) DC., Carolina snailseed, 2150.

MORACEAE

Morus rubra L., red mulberry, 1907.

OLEACEAE

Forestiera acuminata (Michx.) Poiret, eastern swamp-privet, 2026.

Forestiera ligustrina (Michx.) Poiret, upland forestiera, *s.n.*

Fraxinus pennsylvanica Marshall, green ash, 2124.

* *Ligustrum* aff. *lucidum* Aiton, wax leaf privet, sight record.

* *Ligustrum sinense* Lour., Chinese privet, 2803.

ONAGRACEAE

Gaura parviflora Lehm., velvet-leaf beeblossum, 2097.

Ludwigia glandulosa Walter, cylindric-fruit primrose-willow, 2084.

Ludwigia repens J. R. Forst., creeping primrose-willow, 2242.

Oenothera speciosa Nutt., pink evening-primrose, 1862.

OXALIDACEAE

* *Oxalis debilis* Kunth var. *corymbosa* (DC.) Lourteig, pink woodsorrel, 2469.

Oxalis dillenii Jacq., woodsorrel, 2206.

Oxalis violacea L., violet woodsorrel, 2391.

PASSIFLORACEAE

Passiflora incarnata L., purple passionflower, 2205.

Passiflora lutea L., yellow passion flower, 2330.

PHYTOLACCACEAE

Phytolacca americana L. var. *americana*, polk-salad, 2683.

PLANTAGINACEAE

Plantago rhodosperma Decne., red-seed plantain, 1859.

POLYGONACEAE

Brunnichia ovata (Walter) Shinnery, American buckwheat-vine, 2183.

Polygonum hydropiperoides Michx., swamp smartweed, 2085.

Polygonum pensylvanicum L., Pennsylvania smartweed, 2357.

Polygonum punctatum Elliot, water smartweed, 1757.

Polygonum ramosissimum Michx. var. *ramosissimum*, bushy smartweed, 2240.

Polygonum setaceum Baldwin var. *interjectum* Fernald, bristly smartweed, 2525.

Rumex chrysocarpus Moris, golden-fruited dock, 2575.

**Rumex pulcher* L., fiddle dock, 2930.

Rumex verticillatus L., swamp dock, 2099.

Tovara virginiana (L.) Raf., Virginia jumpseed, 2238.

PRIMULACEAE

**Anagallis arvensis* L., common speedwell, 1775.I

**Anagallis minima* (L.) E. H. L. Krause, small pimpernel, 2795.

Samolus valerandi L. subsp. *parviflorus* (Raf.) O. Hultén, Valerand's small-flowered brookweed, 1805.

RANUNCULACEAE

Anemone berlandieri Pritzel, ten-petal anemone, 1770.

Clematis crispa L., swamp clematis, 2229.

Ranunculus hispidus Michx. var. *nitidus* (Chapm.) T. Duncan, glowing bristly buttercup, 2439.

**Ranunculus muricatus* L., spiny-seed buttercup, 1888.

**Ranunculus platensis* A. Spreng., prairie buttercup, 2456.

Ranunculus pusillus Poiret, low buttercup, 2468.

**Ranunculus sardous* Crantz, hairy buttercup, 1771.

RHAMNACEAE

Berchemia scandens (Hill) K. Koch, Alabama supplejack, 1896.

Rhamnus caroliniana Walter, Indian cherry, 2010.

ROSACEAE

Crataegus aff. *spathulata* Michx., little-hip hawthorn, 2885.

Crataegus glabriuscula Sarg., hawthorn, 2255. endemic (duplicate at UWO)

Crataegus series Molles, hawthorn, 2473. (duplicate at UWO)

Crataegus viridis L. var. *viridis*, green hawthorn, 2256. (duplicate at UWO)

Geum canadense Jacq. var. *camporum* (Rydb.) Fernald & Weath., white avens, 1948.

Prunus caroliniana Aiton, Carolina cherry-laurel, 1766.

Rubus argutus Link, highbush blackberry, 1878.

Rubus trivialis Michx., southern dewberry, 2419.

RUBIACEAE

Cephalanthus occidentalis L. var. *californicus* Benth., button-bush, 2181.

Diodia virginiana L., Virginia buttonweed, 2211.

Galium aparine L., catchweed bedstraw, 1872.

* *Galium tinctorium* (L.) J. Scopoli, dye bedstraw, 1868.

* *Sherardia arvensis* L., pink spurwort, 1774.

RUTACEAE

Zanthoxylum clava-herculis L., Hercules' club, 2924.

SALICACEAE

Salix nigra Marshall, black willow, 1898.

SAPINDACEAE

Cardiospermum halicacabum L., common balloon-vine, 2092.

Sapindus saponaria L. var. *drummondii* (Hook. & Arn.) L. D. Benson, Drummond's western soapberry, 2079.

SAPOTACEAE

Sideroxylon lanuginosum Michx. subsp. *oblongifolium* (Nutt.) T. D. Penn., gum bumelia, 2137.

SAURURACEAE

Saururus cernuus L., lizard's-tail, 2070.

SCROPHULARIACEAE

Castilleja indivisa Engelm., Indian paintbrush, 2117.

Gratiola virginiana L. var. *virginiana*, Virginia hedge-hyssop, 1885.

Mecardonia procumbens (Mill.) Small, yellow flowered mecardonia, 2123.

Penstemon tenuis Small, sharp-sepal beard-tongue, 1889.

Veronica peregrina L., purslane speedwell, 1780.

SOLANACEAE

Physalis angulata L., cut-leaf groundcherry, 2109.

Solanum carolinense L. var. *carolinense*, Carolina nightshade, 2110.

STERCULIACEAE

Melochia pyramidata L. var. *pyramidata*, angle-pod broomwood, 2121.

TILIACEAE

Corchorus hirtus L. var. *glabellus* A. Gray, smooth orinoco jute, 2214.

ULMACEAE

Celtis laevigata Willd. var. *laevigata*, sugar hackberry, 1884.

Ulmus americana L., American elm, 2241.

Ulmus crassifolia Nutt., cedar elm, 2360.

URTICACEAE

Boehmeria cylindrica (L.) Sw., false-nettle, 2071.

Parietaria pensylvanica Muhl. ex Willd., Pennsylvania pellitory, 2931.

Urtica chamaedryoides Pursh, heart-leaf stinging-nettle, 1803.

VALERIANACEAE

Valerianella woodsiana (Torr. & A. Gray) Walp., Woods' cornsalad, 1912.

VERBENACEAE

Callicarpa americana L., American beautyberry, 2133.

Phyla lanceolata (Michx.) Greene, lance-leaf frogfruit, 2147.

* *Verbena bonariensis* L., South American vervain, 2220.

Verbena halei Small, Texas vervain, 2175.

* *Verbena litoralis* Kunth, [Sy = *Verbena brasiliensis* Vell.], Brazilian vervain, 1899.

Verbena urticifolia L. var. *urticifolia*, nettle-leaf vervain, 2134.

VIOLACEAE

Viola sororia Willd. var. *sororia*, bayou violet, 1772.

VISCACEAE

Phoradendron tomentosum (DC.) Engelm. ex A. Gray, mistletoe, 2400.

VITACEAE

Ampelopsis arborea (L.) Köhne, pepper-vine, 2101.

Ampelopsis cordata Michx., raccoon grape, 2925.

Parthenocissus quinquefolia (L.) Planch. var. *quinquefolia*, Virginia creeper, 2227.

Vitis aestivalis Michx. var. *aestivalis*, summer grape, 1901.

Vitis cinerea (Engelm.) Engelm. ex Millardet var. *cinerea*, sweet winter grape, 1902.

Vitis mustangensis Buckley, mustang grape, 1879.

Vitis palmata Vahl, catbird grape, 2182.

Asa soils at Dance Bayou are slightly acid to basic silty clay loams in slightly higher convex or nearly level positions on natural levees adjacent to active and abandoned stream channels (Table 2). Pledger soils are basic calcareous clays in broad nearly level flats or concave abandoned stream channels of the Columbia Bottomlands (Table 2). In undisturbed nonponded areas, Pledger soils have typical vertisol gilgai microtopography that consists of interconnected microhighs and small isolated microlows. Microlows make up about 10 percent of the area and range from oval areas 100 to 200 cm in diameter to oblong areas 100 to 300 cm long and 50 to 100 cm wide. Elevation difference between the bottom of the microlow and the top of the microhigh averages about 13 cm and ranges from 6 to 20 cm.

DISCUSSION

The 263 ha Dance Bayou unit has high native plant species richness (301 sp.; Table 1). Nixon (1986) reported native woody species richness ranged from 5 to 51 species in various bottomland hardwood plant communities in east Texas. Fifty-three native

Table 2. Select Asa and Pledger soil properties including particle size distribution, texture class, pH, organic matter content, and chemical analysis. Parameters not measured are indicated by a dash (-).

Soil	Horizon	Depth (cm)	Particle size (%)			Texture Class ^a	pH	Organic Matter (%)	Ca	Mg	Na	K	Fe (%)	Mn (%) ^b
			sand	silt	clay									
meq · 100 g ⁻¹														
Asa	A1	0-16	14	49	37	SiCL	6.8	3.1	23.1	2.4	0.1	0.8	-	-
	A2	16-40	21	46	33	CL	7.6	1.9	51.1	2.1	0.1	0.6	-	-
	Bw	40-75	11	58	31	SiCL	7.6	0.9	49.5	1.8	0.1	0.4	-	-
	Bk	75-100	9	56	35	SiCL	8.0	0.6	58.6	3.9	0.1	0.5	-	-
Pledger	A	0-14	1	25	74	C	7.2	7.1	40.6	5.0	0.2	2.2	1.9	0.1
microlow	Bss	14-100	1	25	74	C	7.0	5.4	60.3	5.4	0.1	1.7	2.0	0.1
Pledger	A	0-10	6	27	67	C	7.4	5.3	-	4.4	0.4	1.7	2.1	0.1
microhigh	Bw	10-46	6	26	68	C	7.6	5.0	-	4.4	0.5	1.4	2.0	Tr
	Bss	46-100	7	33	60	C	7.8	1.0	-	7.1	0.8	0.7	1.8	Tr

^aSiCL-Silty Clay Loam, CL-Clay Loam, C-Clay. ^b Tr-trace (<0.1).

woody species occur at the Dance Bayou unit; the visual dominant over-story species across all landscape positions include *Fraxinus pennsylvanica* (green ash), *Quercus virginiana* var. *virginiana* (live oak), *Celtis laevigata* var. *laevigata* (sugar hackberry), *Ulmus crassifolia* (cedar elm), *Sapindus saponaria* var. *drummondii* (Drummond's western soapberry), *Q. nigra* (water oak), and *U. americana* (American elm). Dominant woody species at the Dance Bayou unit are similar to those previously reported from virgin east Texas forests, as well as bottomlands and riparian forests of north-central Oklahoma and the Edwards Plateau in south-central Texas (Nixon et al. 1977; 1991).

Several endemic species were encountered at the Dance Bayou unit. *Crataegus glabriuscula* (hawthorn) occurs in dry creek beds and bottomlands in north central and south Texas; *Erigeron geiseri* var. *geiseri* (Geiser's fleabane) occurs in open and usually sandy sites in central Texas; *Herbertia lahue* (South Texas herbertia) occurs in clayey or sandy soils in prairies of south Texas; and *Spigelia texana* (Texas pinkroot) occurs in wooded slopes and floodplain woods in south Texas (Correll & Johnston 1970). *Carex lupuliformis* (hop-like caric-sedge) occurs from Quebec, south to Florida and west to Texas, though it is always rare within its range (Jones & Hatch 1990). Several large populations of false hop-like caric-sedge occur in forested wetlands on Pledger soils in the Dance Bayou unit. Sixteen native plant species listed by Barrow et al. (2000) as important food resources for Nearctic-Neotropical migrant landbirds occur at the Dance Bayou unit. Of the 53 native woody species that occur at Dance Bayou, only 16 occur as canopy; the remainders are sub-canopy, shrubs, sub-shrubs, or vines. The numerous sub-canopy, shrub and vine species found beneath the forest canopy as well as in tree fall gaps contribute greatly to the structural architecture of the forest. Thus, under-brushing, thinning, and grazing will greatly decrease plant species richness and structural complexity in the Columbia Bottomlands.

Non native plant species were observed to be restricted to disturbed areas such as right-of-ways, roadsides, forest edges, and clearings, with two troubling exceptions. Tree fall gaps and seasonally flooded forested wetlands are susceptible to colonization by *Triadica sebifera* (Chinese tallow-tree). Invasions in tree fall gaps could potentially alter gap succession with disastrous effects on forest dynamics. Draw-downs of surface water in forested wetlands, whether during drought or seasonal dry cycles, facilitate infestations. *Cyperus entrerianus* (deeprooted sedge) is a pernicious weed and appears to be a serious threat to native plant diversity in the Columbia Bottomlands. Deeprooted sedge typically establishes along roadside and right-of-ways, and then advances through forest edges into undisturbed areas under closed-canopy forest. Other potentially problematic non native species at the Dance Bayou unit, and throughout the Columbia Bottomlands, include *Albizia julibrissin* (mimosa tree), *Melia azedarach* (Chinaberry tree), *Ligustrum* sp. (privet), and *Lonicera japonica* (Japanese honeysuckle). A Federally listed noxious weed, sessile joyweed, was encountered once along the banks of Dance Bayou early in this study, but has not been seen since.

Results of this study indicate that old-growth Columbia Bottomland forests are characterized by high native plant species richness, frequent tree falls followed by gap succession, large vines, abundant epiphytic growth, and conspicuous microtopography. Activities such as under-brushing, thinning, and grazing will greatly decrease plant species richness and available structural complexity. Attention should be given to non native species, and early detection and eradication, followed by periodic monitoring are warranted. The once vast forests adjacent to the Brazos, Colorado, and San Bernard rivers of the upper Texas coast remain today as remnant forest patches. Because of rapidly spreading commercial and residential development of the Houston Metroplex, much of the native flora of the Columbia Bottomlands may ultimately disappear.

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ASCIDIANS OF SOUTH PADRE ISLAND, TEXAS,
WITH A KEY TO SPECIES

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Abstract.—The ascidians of South Padre Island, Texas were surveyed in August 2004. Because the subtidal area is limited to soft sediments, the survey was restricted to marina floats and pilings, harbor buoys, boat hulls and other artificial substrates which offer suitable attachment surfaces for ascidians. Fifteen species were documented, with multiple species representing each of the three orders of ascidians. None of the species found in this survey are native, suggesting they were all introduced through boat traffic. About half the species were found in a reproductive state, however, indicating that they have established local breeding populations.

Ascidians are marine invertebrate chordates, some of which are classic model organisms for the study of development and evolution (Conklin 1905; Berrill 1932; Satoh 1994; Corbo et al. 2001). They are emerging model organisms for other fields, including genetics (Dehal et al. 2002; Satoh et al. 2003), immunology (Azumi et al. 2003; Khalturin et al. 2003; Du Pasquier 2004; Rinkevich 2004), and neurobiology (Meinertzhagen & Okamura 2001; Meinertzhagen et al. 2004). Ascidians are also attracting attention as potential bio-indicators of environmental health (Cima et al. 1995; Cima et al. 1997) and as seafood, particularly in Japan and Korea (Sawada et al. 2001). Ascidians are efficient filter feeders, and certain species with wide environmental tolerances have become highly invasive, especially in bays and harbors where they compete with and overgrow commercial shellfish (Lesser et al. 1992; Carver et al. 2003) and create a significant fouling community on boat hulls and marina floats (Teo & Ryland 1995; Hodson et al. 2000; Lambert 2001; 2002; Lambert & Lambert 2003). Thus, locales with

high ascidian populations hold great potential for scientific and commercial research.

Most ascidian species require a hard substrate for attachment. The natural subtidal substrates along most of the Texas coast are composed of soft sediments. Thus, prior to the establishment of man-made substrates (marina floats, pilings, harbor buoys and boat hulls), few shallow-water ascidians were recorded from the Texas Gulf coast (Van Name 1945; Whitten et al. 1950; Van Name 1954). Informal observations indicate that the south Texas coast may support ascidians in greater abundance than the rest of the Texas coastline. This paper lists the 15 species observed during a recent survey around South Padre Island, their locations and abundance, and includes a taxonomic key to species.

METHODS

Individuals were collected from the waters of the Laguna Madre around the southern end of South Padre Island, Texas, on 7-8 August 2004. Collection locations were identified using the global positioning system (GPS). Figure 1 shows the six collection sites: (a) Sea Ranch marina ($26^{\circ} 4' 33.4''$ N, $97^{\circ} 9' 52.8''$ W); (b) Parrot Eyes marina ($26^{\circ} 8' 0.4''$ N, $97^{\circ} 10' 36.9''$ W); (c) Laguna Madre boat canal mid-channel buoy ($26^{\circ} 4' 1.2''$ N, $97^{\circ} 10' 0.6''$ W); (d) the Coastal Studies Lab seawater intake support ($26^{\circ} 4' 4.9''$ N, $97^{\circ} 9' 49.1''$ W); (e) Port Isabel deep water docks ($26^{\circ} 3' 30.0''$ N, $97^{\circ} 12' 49.4''$ W), and; (f) Billy Kenan's dock ($26^{\circ} 3' 56.8''$ N, $97^{\circ} 12' 54.6''$ W).

Specimens were initially examined live under dissecting microscopes, with further examination of some species after preservation. Representative individuals were fixed either directly in 70% ethanol or relaxed in seawater containing a few drops of a concentrated menthol/ethanol solution, and then preserved in 10% seawater formalin buffered with sodium borate.

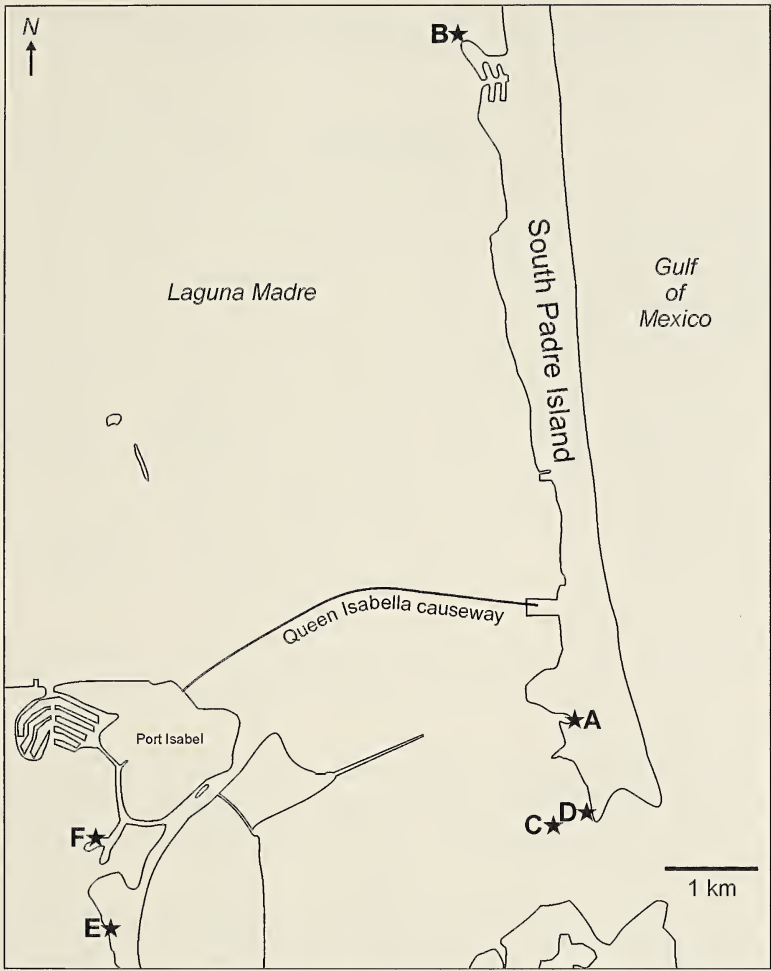


Figure 1. Map of South Padre Island area, Texas, showing collection sites of ascidians. a = Sea Ranch marina; b = Parrot Eyes marina; c = Laguna Madre boat canal mid-channel buoy; d = Coastal Studies Lab seawater intake support; e = Port Isabel deep water docks; f = Billy Kenan's dock (sites listed in order visited).

Specimens were identified at least to genus level. The primary sources used for identification were (Van Name 1945; Plough 1978); *Didemnum duplicatum* was identified from (Monniot 1983). Labelled voucher specimens were deposited in the Coastal Studies Laboratory on South Padre Island.

Table 1. Systematic listing of species collected. Locations as given in Methods and Figure 1.

Taxon	Location(s) collected	Solitary or Colonial	Reproductive Status during Survey
Phylum Chordata			
Subphylum Tunicata			
Class Ascidiacea			
Order Aplousobranchia			
Family Didemnidae			
<i>Didemnum psammathodes</i>	b	Colonial	Not productive
<i>Didemnum duplicatum</i>	b, c	Colonial	Brooded larvae
<i>Diplosoma listerianum</i>	b	Colonial	Brooded larvae
<i>Lissoclinum fragile</i>	a, b	Colonial	Not productive
Family Polyclinidae			
<i>Polyclinum constellatum</i>	b, e	Colonial	Not productive
Family Clavelinidae			
<i>Clavelina oblonga</i>	d	Colonial	Brooded larvae
Order Phlebobranchia			
Family Perophoridae			
<i>Perophora</i> sp.	a, e	Colonial	Not productive
Family Ascidiidae			
<i>Ascidia interrupta</i>	a	Solitary	Not productive
Order Stolidobranchia			
Family Styelidae			
<i>Botrylloides nigrum</i>	b, e	Colonial	Not productive
<i>Botrylloides</i> sp.	c, e, f	Colonial	Brooded larvae
<i>Polyandrocarpa zorritensis</i>	e, f	Colonial	Not productive
<i>Styela canopus</i>	a, b, e	Solitary	Ripe gonads
<i>Styela plicata</i>	a, b, e, f	Solitary	Ripe gonads
<i>Symplegma viride</i>	e	Colonial	Not productive
<i>Symplegma rubra</i>	a, e, f	Colonial	Brooded larvae

RESULTS

Fifteen species of ascidians were identified in this survey (Table 1). *Styela plicata*, *S. canopus*, and *Lissoclinum fragile* were particularly abundant, with *S. plicata* being found in large numbers at four of the six collection sites. Several other species that are small or inconspicuous may also be more common or abundant than indicated by this survey. Seven species were reproductive at the time of the survey, indicating that these species have formed locally reproductive populations. *Ascidia interrupta*, though rare during

this survey, is abundant in autumn and is reproductive during that time.

KEY TO SPECIES

“There are some groups of animals for which keys can be made that really work in a considerable number of instances, but the ascidians are not among them” (Van Name 1945). This key is specific for the organisms seen or previously collected in these bays but is not necessarily valid for other regions. It is based on a 7-9 August 2004 survey of South Padre Island; there may be additional species more abundant at other times of the year that are not included here. An asterisk (*) indicates species not found during this survey but which are expected due to their distribution: *Ciona intestinalis* has a cosmopolitan distribution, and *Molgula manhat-tensis* has been recorded elsewhere in Texas.

Explanations of terms, species descriptions, and illustrations can be found in Van Name (1945) or Plough (1978).

- 1. Solitary ascidians; each zooid enclosed in its own tunic..... 2
Colonial ascidians; multiple zooids within a common tunic or connected by stolons..... 6
- 2. Branchial sac without internal longitudinal folds..... 3
Branchial sac with four or more prominent internal longi-tudinal folds..... 4
- 3. Body wall (easily visible inside smooth transparent tunic) with five to seven white wide longitudinal muscle bands on each side (often somewhat contracted in fixed animals); animal elongate, flaccid, attached basally *Ciona intestinalis**
Body wall muscles in a meshlike pattern mostly on right (uppermost) side but not as above; animal attached broadly on left side, tunic semi-transparent, thin and not smooth
..... *Ascidia interrupta*

- | | | |
|----|---|--|
| 4. | Tunic thin, semi-transparent but usually muddy; body spherical, 2-4 cm in diameter; oral siphon with six lobes, atrial siphon with four lobes; six branchial folds per side | <i>Molgula manhattensis</i> * |
| | Tunic leathery; four branchial folds per side..... | 5 |
| 5. | Tunic brownish, furrowed; body usually 2-3 cm in height; siphon tips with numerous mottled reddish stripes; two long slender ovaries/side; testes large, white, often bifurcated, attached to posterior end of ovaries by long threadlike sperm ducts | <i>Styela canopus</i> |
| | Tunic white with large rounded soft lumps; body up to 10 cm in height; siphon tips with four black stripes; two gonads on left side, five on right; testes small and attached along most of the length of each ovary | <i>Styela plicata</i> |
| 6. | Multiple zooids connected by stolons, each zooid enclosed by separate tunic | 7 |
| | Multiple zooids all embedded in common tunic | 9 |
| 7. | Zooids spherical or up to twice as long as wide..... | 8 |
| | Zooids over four times as long as wide, transparent, colorless. | <i>Clavelina oblonga</i> |
| 8. | Tunic soft and fragile, zooids globular, pale green, translucent, 2-4mm in height; branchial sac with four rows of stigmata ... | <i>Perophora</i> sp. (probably <i>P. viridis</i>) |
| | Tunic tough and leathery, zooids elongate, dark brown or purple, up to 2 cm in height; stolons usually coalesced into a basal mat; branchial sac with more than four rows of stigmata | <i>Polyandrocarpa zorritensis</i> |
| 9. | Zooids not divided into body regions; vascular ampullae present in tunic | 10 |
| | Zooids divided into two or three distinct regions; vascular ampullae absent in tunic | 13 |

- 10. Zooids (2.5-4 mm) flat, never organized in systems, widely spaced with clear tunic between, both siphons open at colony surface 11
- Small zooids (<2 mm), organized in systems, only branchial siphon opens to surface of colony, densely spaced with little tunic between..... 12

- 11. Zooids red, tunic opaque *Symplegma rubra*
Zooids translucent with greenish or multicolored flecks of pigment..... *Symplegma viride*

- 12. Zooids in elongate systems, colony a single color, usually purple or orange, vertically oriented in tunic, testis ventral (on side with incurrent siphon) and anterior to single ovary, stomach lobes bulbous at ends.....
..... *Botrylloides nigrum*
Zooids in elongate systems, two colors in colony, dark basic colony color, bright yellow around siphonal area.....
..... *Botrylloides* sp.

- 13. Zooids with two body regions (thorax, abdomen), colony thin and encrusting, zooids with four rows of stigmata 14
Zooids with three body regions (thorax, abdomen, post-abdomen), colony dark, thick and encrusting, may be dome shaped, zooids in circular systems, each zooid with 14-18 rows of stigmata *Polyclinum constellatum*

- 14. Tunic with tiny (visible with compound microscope) white spherical calcareous spicules with many short pointed rays, mostly in surface layer of colony..... 15
Colony lacking calcareous spicules though there may be considerable white pigment granules; tunic transparent, very flaccid, zooids tiny (2-3 mm in length) usually with black pigment on thorax and abdomen..... *Diplosoma listerianum*

15. Atrial opening small or moderate size; sperm duct spirally coiled, colony not white and easily torn 16
Atrial opening large, exposing most of branchial walls; sperm duct not spirally coiled, colony white, tunic very fragile and easily torn*Lissoclinum fragile*
16. Colony distinctly muddy gray colored due to numerous fecal pellets stored in the tunic *Didemnum psammathodes*
Colony salmon colored, leathery, with meandering dark lines .
.....*Didemnum duplicatum*

DISCUSSION

A diverse assemblage of ascidian species is present in considerable abundance along the southern Texas coastline. All of the species found in this survey are apparently non-native and have most likely been introduced on boat hulls. All have been recorded elsewhere in the Gulf of Mexico, on the Atlantic side of Florida, or various regions of the Caribbean as well as other warm water regions of the world (Lambert 2001; 2002). All are shallow-water species not recorded in the survey of (presumably native) deep-water ascidians of the Gulf of Mexico (Monniot & Monniot 1987), though a few were recorded from continental shelf depths of the Gulf (Plough 1978). Given that five colonial species contained brooded larvae, and two of the three solitary species had ripe gonads, it seems likely that many or most of the species found have formed breeding populations in the local waters.

The species sampled include more than one member of each of the three orders in class Ascidiacea, providing substantial diversity for comparative research. Indeed, the prospects for future research on ascidians in this area are extremely good. Many of the genera found on South Padre Island have been the focus of substantial research. For example, the natural pigmentation of *Styela* embryos enabled classic studies of chordate development (Conklin 1905; Gehring 2004). Colonial tunicates like *Botrylloides* are now model

organisms for allorecognition and the evolution of immune responses (Scofield et al. 1982; Scofield & Nagashima 1983; Rinkevich 1995; Hirose et al. 1997; Paz & Rinkevich 2002; Rinkevich 2004). Several of the ascidian genera on South Padre Island have been the source of many novel chemical compounds, including some with possible therapeutic properties, including *Didemnum* (Kang & Fenical 1997; Smith et al. 1997; Davis et al. 1999; Mitchell et al. 2000; Oku et al. 2003), *Lissoclinum* (Badre et al. 1994), *Styela* (Lee et al. 1997a; Lee et al. 1997b; Zhao et al. 1997) and *Symplegma* (Lindsay et al. 1999).

The collecting sites are conveniently located near a well-equipped research and teaching laboratory (Coastal Studies Laboratory, University of Texas-Pan American). All the species described here should be easily maintained alive in the large seawater tanks, especially if placed in floating plastic sieves or grown on glass plates, or easily collected for same-day use. Most of the species have long breeding seasons and are easy to remove gametes from (for solitary species) or brooded embryos (for colonial species). Development of solitary species is very rapid (less than 24 hours to hatching) and the larvae of all ascidians are short-lived and non-feeding, allowing metamorphosis and post-metamorphic events to be followed easily. The readily available ascidians of South Padre Island also provide highly suitable material for classroom use in a number of teaching areas.

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EFFECTS OF INSECTICIDE (CARBARYL) EXPOSURE
ON ACTIVITY AND SWIMMING PERFORMANCE
OF TADPOLES OF THE RIO GRANDE LEOPARD FROG,
RANA BERLANDIERI (ANURA: RANIDAE)

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Abstract.—Experiments were conducted to assess the effects of the insecticide carbaryl on proportion of time spent in activity (tail movement) and swimming speed of tadpoles of the Rio Grande Leopard Frog, *Rana berlandieri*. Tadpoles were exposed (0 to 96 h) to various concentrations of carbaryl (3.5, 5.0 or 7.5 mg/L), or to an acetone solvent control, or water control. No significant differences in behavior were observed between tadpoles of either control group. Time spent in activity and swimming speed decreased significantly at all concentrations of carbaryl after 24 h exposure, and this effect was most pronounced at 7.5 mg/L. Full recovery of time spent in activity was observed for tadpoles exposed to 3.5 mg/L carbaryl when tested at 48 h post-exposure. Tadpoles exposed to 5.0 mg/L recovered to a lesser extent and exhibited activity levels of approximately 52% of those exhibited by controls, and tadpoles exposed to 7.5 mg/L carbaryl showed no recovery at 48 h post-exposure. Swimming speed decreased significantly for tadpoles exposed to 3.5 mg/L carbaryl after 48 h exposure, whereas exposure to 5.0 mg/L resulted in a significant reduction after only 24 h. In tadpoles, swimming speed is important for carrying out certain life history functions such as growth and development. A decrease in swimming speed may result in higher predation rates (increased mortality), as well as slower growth rates thereby increasing the amount of time required to complete metamorphosis. Exposure to pesticides must be considered when analyzing possible causes of amphibian declines.

Although studying the responses of animals to lethal concentrations of toxic substances is necessary to obtain reliable indices of sensitivity to contaminants, analyzing the effects of exposure to sublethal concentrations may provide more valuable and ecologically-relevant information. Exposure to sublethal levels frequently affects behavior, often in subtle ways, that can result indirectly in death, or in the alteration of certain life history functions such as growth and development. Behaviors that may be adversely affected include performance on motor tasks (Punzo & 2003), foraging activities (Little et al. 1990), maternal behavior (Punzo 2003), and

reduced capacity to escape from predators (Jung & Jagoe 1994), as well as learning and memory processes (Punzo & Farmer 2004).

Because of their biphasic life histories (aquatic larval stage followed by a more terrestrial adult stage) and highly permeable integument, amphibians are particularly susceptible to chemical contaminants found in aquatic and terrestrial habitats. They breed in permanent as well as ephemeral bodies of water that often receive large amounts of runoff from roads, storm drains, and adjacent agricultural landscapes. Acidic deposition, pesticides, herbicides, and other forms of pollutants are thus carried into a variety of aquatic habitats, posing a threat to amphibian eggs and tadpoles. Because of the attention that has been given to the alarming worldwide decline in amphibian populations (Blaustein & Wake 1990; Houlihan et al. 2001), researchers have recognized the importance of conducting ecotoxicological studies on amphibians.

The Rio Grande leopard frog, *Rana berlandieri* (Anura: Ranidae) is distributed throughout central and west Texas, southern New Mexico, and south into Mexico (Conant & Collins 1998). It is found along rivers, in permanent and temporary ponds, and stock tanks, in mesic and xeric habitats. In west Texas, it occurs along the Rio Grande River (RGR), from El Paso, through the Big Bend region of Trans Pecos Texas. The RGR slices through extensive agricultural fields between the U.S. and Mexico in Presidio County, Texas. A variety of pesticides and herbicides are used in this area, including carbamate insecticides such as carbaryl (Aspelin 1992).

Carbaryl (1-naphthyl-*N*-methylcarbamate) is a broad-spectrum insecticide used to control injurious insects, and current usage in the U.S. ranges from 2500 to 3500 metric tons/year (Bridges 2000). Field concentrations up to 4.8 mg/L have been reported immediately following application (Norris et al. 1983), and carbaryl may persist in aquatic ecosystems for over a year (Gibbs et al. 1984). Carbamates inhibit acetylcholinesterase (AChE) activity in the central nervous system resulting in paralysis and death at higher

concentrations. In anuran tadpoles, sublethal concentrations of carbaryl can cause a variety of adverse effects including developmental deformities (Ouellet et al. 1997), impairment of growth and metamorphosis (Marian et al. 1983), and a decrease in locomotor activities (Berrill et al. 1994; Bridges 1997).

An increase in the use of carbamate pesticides in west Texas (Applegate & Bath 1983; Ouellet et al. 1997) has been coupled with a decline in density of some populations of *R. berlandieri* (cf. Garrett & Barker 2001). Additionally, *R. berlandieri* may be expanding parts of its range (Berger 1989), and although this species has not shown an overall decline, the response of an apparently thriving species to contaminants may provide data for assessing pesticide effects on *R. berlandieri* populations in the future. Because no data are available on the effects of carbamates on this species, this study assessed the effects of sublethal concentrations of carbaryl on general level of activity (tail movements) and swimming speed in tadpoles of *R. berlandieri*.

MATERIALS AND METHODS

Adult frogs were collected during the spring of 2002 along the Rio Grande floodplain adjacent to the RGR, at several locations off of State Route 170, Presidio County, Texas. This area lies within the northern region of the Chihuahuan Desert. Twenty-two egg masses deposited by *R. berlandieri* females from sites where breeding males and females had been observed were brought into the laboratory and placed in 10-L glass bowls containing aerated, dechlorinated well water. Bowls were maintained at $23 \pm 0.2^{\circ}\text{C}$ under a 12L:12D photoperiod regime in Precision Model 85 environmental chambers (Boone, Iowa). Using eggs deposited in captivity ensures that those used in experiments had no prior exposure to toxic chemicals. Water in bowls was changed every other day, and after hatching, tadpoles were maintained in groups of 20/bowl and fed ad libitum on a diet of commercial tadpole food pellets (Carolina Biological Supply, Burlington, North Carolina). Tadpoles were deprived of food for 24 hr prior to testing and were not

fed during experiments. Only tadpoles that had reached stage 25 of development (Gosner 1960) were used for testing.

All experiments were conducted using aerated well water (pH: 7.6, hardness: 286 mg/L CaCO_3 ; alkalinity: 258 mg/L CaCO_3). Reagent grade acetone (Sigma, St. Louis, Missouri) was used as a solvent for carbaryl and as a solvent control. Acetone concentrations were never in excess of 0.45 mL/L. Technical grade carbaryl (Rhône-Poulec, Research Triangle Park, NC: 99.7% purity, 6.02g) dissolved in 100 mL acetone comprised the stock solution used for all experiments.

Tadpole behavior was analyzed in three sublethal concentrations of carbaryl: 3.5 (low concentration), 5.0 (medium) and 7.5 (high) mg/L, as well as in a water control, and solvent (acetone) control. Low, medium and high carbaryl designations represent 72-75, 63-65 and 50-51%, respectively, of published LC50 values for other ranid frogs (Kanega 1979; Berger 1989). These concentrations of carbaryl were also chosen on the basis of known concentrations of carbaryl in aquatic habitats within agricultural landscapes in the southwest (Applegate & Bath 1983), and on concentrations used in previous studies on other species of ranid frogs (Bridges & Semlitsch 2000).

Two groups (replicates), each consisting of five 4-L glass bowls (filled with 2 L of aerated well water), were placed in each of two water baths ($23 \pm 0.2^\circ\text{C}$), for a total of 10 replicates. After adding the appropriate amount of carbaryl to each bowl, a single tadpole was randomly assigned to each bowl and given a 30-min acclimation period before recording their behavior. Each subject was observed for a 5-sec period every four min to assess swimming or resting activities. Activity was defined as any movements of the tail (Jung & Jagoe 1994). Observations were repeated 20 times/jar (total of 80 min), and the proportion of 5-sec observation periods that tadpoles were active was determined. Following observations,

tadpoles were gently prodded with a glass stirring rod to ensure that immobile animals were alive. Observations of activity were conducted at 0, 0.5, 48, and 96 h. Following the 96-h observation, tadpoles were placed in fresh well water and fed 15 mg of tadpole food pellets. Post-exposure activity was then observed at 48 h. All tests were recorded with a Panasonic video recorder.

All statistical analyses followed procedures described by Sokal & Rohlf (1995). Proportion of time spent being active was transformed (arcsine-square root), and effects of carbaryl treatments were analyzed using a 2 x 5 factorial analysis of variance (*ANOVA*) with water bath as a blocking factor, and time as a repeated measure. Pairwise comparisons among treatments were analyzed using Bonferroni multiple *t*-tests.

For swimming performance tests, tadpoles were exposed to one of three carbaryl concentrations (3.5, 5.0, 7.5 mg/L), a solvent (acetone) control (SC), or a water control (WC). Ten groups (replicates) consisting of five exposure chambers were placed in water baths ($23 \pm 0.2^\circ\text{C}$) and randomly assigned to a treatment condition. An appropriate amount of carbaryl or acetone was pipetted into 4-L glass bowls filled with 2 L of well water, and stirred for three min.

Swimming performance was studied in a square-shaped, stainless steel chamber (each side: 1.0 m in length; 25 cm in depth). A plexiglass sheet was cut to fit the bottom of the chamber, and provided with a grid divided into 1 by 1 cm squares, drawn with water-proof ink. The bottom of the tank was painted white to enhance the contrast of the grid lines. For testing, the tank was filled to a depth of 15 cm and maintained at $23 \pm 0.2^\circ\text{C}$ with an electric water heater. All tests were recorded with a Panasonic video recorder that was placed 1.5 m above the tank. Swimming performance was recorded as swimming (sprint) speed (in cm/sec) for each tadpole. Tadpoles were tested at the beginning of a trial (0), and again at 24, 48, 72 and 96 h of exposure.

Table 1. Proportion of time spent in activity (moving their tails) by tadpoles of *Ranaberlandieri* at 0.5, 48 and 96 h post-exposure in three carbaryl concentrations (3.5, 5.0 or 7.5 mg/L), in a solvent (acetone) control (SC), or water control (WC). Controls differed significantly from all carbaryl concentrations at 0.5, 48 and 96 h. ($P < 0.001$). Data expressed as means; values in parentheses represent $\pm 1 SE$. Tob = time of observation.

Treatment	Tob (hr):	Proportion of time spent active			
		0.5	48	96	48 post-exposure
3.5 mg/L		0.22 (0.01)	0.25 (0.01)	0.27 (0.02)	0.44 (0.02)
5.0 mg/L		0.08 (0.01)	0.06 (0.01)	0.05 (0.02)	0.24 (0.01)
7.5 mg/L		0.06 (0.01)	0.03 (0.01)	0.03 (0.01)	0.04 (0.02)
S C		0.47 (0.04)	0.49 (0.03)	0.52 (0.03)	0.49 (0.05)
W C		0.51 (0.05)	0.47 (0.02)	0.49 (0.04)	0.48 (0.03)

Data on swimming speed were log-transformed (Sokal & Rohlf 1995), and a multivariate analysis of variance (*MANOVA*), with time as a repeated measure, was used to analyze the effects of carbaryl concentration on performance. Individual tadpole performance was included as a main effect to determine if any differences in swimming performance might be attributed to genetic differences among tadpoles. Pairwise comparisons were analyzed using Bonferroni multiple *t*-tests.

RESULTS

Exposure to carbaryl had a significant overall effect on the proportion of time tadpoles spent in activity (moving their tails) ($F = 21.34$, $df = 4, 36$, $P < 0.001$) (Table 1). Time spent in activity was significantly lower for tadpoles under all concentrations of carbaryl as compared to both control groups. There was a mortality of 43% for tadpoles exposed to 7.5 mg/L of carbaryl at 96 h exposure, as compared to 9% at 5.0 mg/L, and 0% at 3.5 mg/L.

Table 2. Swimming performance (in cm/sec) of tadpoles of *Rana berlandieri* with changing carbaryl concentrations over a 96-h exposure period, or to a solvent (acetone) control (SC), or water control (WC). Data expressed as means; values in parentheses represent ± 1 SE. Values in rows and columns followed by a different letter are significantly different ($P < 0.05$).

Treatment condition	Time of exposure (h)				
	0	24	48	72	96
Swimming performance (cm/sec)					
3.5 mg/L carbaryl	9.15a (1.56)	8.94a (0.95)	7.11b (0.73)	6.77b (0.58)	5.15c (0.37)
5.0 mg/L	10.21a (2.04)	6.17c (1.12)	5.88c (0.38)	4.25d (0.41)	4.16d (0.24)
7.5 mg/L	9.86a (1.17)	5.48c (0.23)	5.17c (0.18)	3.57d (0.11)	2.28e (0.14)
SC	9.84a (1.42)	9.37a (1.21)	10.14a (1.42)	9.73a (0.87)	9.86a (1.12)
WC	10.43a (1.87)	9.62a (0.79)	9.53a (0.82)	10.24a (0.71)	8.92a (0.68)

Even at a concentration of 3.5 mg/L carbaryl, tadpole activity was significantly reduced as compared to control groups ($P < 0.01$). There was no significant difference in activity between SC and WC groups. Activity levels tested at 48 h post-exposure increased significantly for tadpoles exposed to 3.5 and 5.0 mg/L carbaryl ($P < 0.05$). However, no recovery was observed for tadpoles exposed to 7.5 mg/L.

The effect of carbaryl on swimming speed is shown in Table 2. There was an overall significant effect of carbaryl concentration on swimming performance ($F = 11.74$, $df = 4, 246$, $P < 0.001$). There was no significant difference in performance between the two control groups, or between any of the treatment conditions at the beginning of the testing period (0 h) ($P > 0.60$). After 24 h of exposure, control tadpoles exhibited faster swimming speed than in any of the carbaryl-exposed groups ($P < 0.01$), with a significant interaction between time and concentration ($F = 9.07$, $df = 24, 216$, $P < 0.01$). Length of exposure also had a significant effect on

swimming speed ($F = 218.56$, $df = 1, 246$, $P < 0.001$). There was also a significant difference in the performance of individual tadpoles ($F = 3.24$, $df = 36, 216$, $P < 0.01$), indicating that some tadpoles are genetically predisposed to faster swimming speed. However, there was no significant interactions between individual tadpoles and any other factor ($P > 0.50$), showing that faster-swimming tadpoles were present across all carbaryl treatments and thus did not significantly influence overall swimming speed.

DISCUSSION

Results clearly show that exposure to carbaryl caused a significant reduction in the amount of time spent in activity as well as a decrease in swimming speed for tadpoles of *Rana berlandieri*. Any impairment of swimming performance may reduce the ability of tadpoles to escape mobile predators (Punzo 1992), thereby reducing overall fitness. In addition, previous research has shown a positive correlation between time spent in activity and length of feeding bouts in anuran larvae (Horat & Semlitsch 1994). Thus, reduced activity may result in shorter and less frequent feeding bouts. This, in turn, may reduce body size of late-stage tadpoles and subsequent metamorphs. It has been established that overall fitness of salamanders (Semlitsch et al. 1988) and anurans (Smith 1987) is dependent on size at metamorphosis. Furthermore, exposure to carbaryl concentrations ranging from 3.0 to 8.0 mg/L have been shown to reduce growth rates in other species of ranid frogs (Marian et al. 1983; Berrill et al. 1994; Bridges 2000). Slower growth rate would lengthen the larval period and thereby increase amount of time tadpoles might be exposed to predators.

These experiments also showed that activity, as measured by tail movement, returned to levels exhibited by control animals after 48 h post-exposure, for tadpoles exposed to 3.5 and 5.0 mg/L carbaryl. However, no similar recovery was observed for animals exposed to 7.5 mg/L. To survive exposure to chemical toxins in aquatic environments, it is important that organisms exhibit an ability to recover and regain bodily functions, either when concentration of toxic

substances decreases, or when animals either move or drift into areas that may have lower levels of these substances.

In conclusion, carbaryl can have adverse effects on several life history functions of ranid tadpoles, leading to a reduction in overall fitness. Thus, exposure to pesticides must be taken into account when addressing factors that may be responsible for amphibian declines.

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BREEDING DISTRIBUTIONS OF SELECTED
CHARADRIIFORMS (CHARADRIIFORMES: CHARADRIIDAE,
SCOLOPACIDAE, LARIDAE) IN INTERIOR TEXAS

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Abstract.—Knowledge of the breeding distributions of Snowy Plovers (*Charadrius alexandrinus*), Spotted Sandpipers (*Actitis macularia*), and Interior Least Terns (*Sterna antillarum athalassos*) in Texas is limited to outdated publications and a lack of recent field surveys. Seventeen lakes or reservoirs in thirteen counties in west-central and east-central Texas were surveyed during the summer months of 1998-2001 for the three bird species. The survey together with other previously unpublished records reveal significant expansion of the breeding distribution of Interior Least Terns and Snowy Plovers in Texas including twenty-one and eight new county records, respectively, along with three new county records for Spotted Sandpipers.

Current knowledge of the breeding distributions of charadriiforms (Aves: Charadriiformes) in Texas is available in regional avifaunal descriptions (Pulich 1988; Lockwood 2001; Seyffert 2001; White 2002) and publications of state or national scope (Oberholser 1974; Texas Ornithological Society 1995; Page et al. 1995; Oring et al. 1997; Thompson et al. 1997; American Ornithologists' Union 1998). Current knowledge of the distributions of Snowy Plover, Spotted Sandpiper, and Interior Least Tern is also limited by a lack of effort to identify new breeding populations in the field. This is due largely to a combination of the logistical difficulties of extensive surveys, lack of experienced observers in the field, and sparsity of reports of breeding birds in Texas (Downing 1980; Husak & Maxwell 2001). The construction of lakes and reservoirs for water needs and flood control throughout the state since the 1950s has changed the landscape considerably and greatly increased the potential for expansion of waterbird

breeding populations. Up-to-date knowledge is important for management of species of concern such as the Snowy Plover and the endangered Interior Least Tern (U.S. Fish and Wildlife Service 1990; 1991). This study provides a review of the current literature on breeding distributions of Snowy Plovers, Spotted Sand-pipers, and Interior Least Terns, and updates the breeding distribution of the three species in the interior of Texas (greater than 50 miles from the coast) with observations made by these authors, other reliable observers in the field, and new records reported in recent literature and the Texas Breeding Bird Atlas Program.

MATERIALS AND METHODS

Sixteen lakes or reservoirs in eleven counties in west-central Texas (Table 1) were each subjected to an extensive one-day survey within the period from 29 May 1998 to 28 July 1998 for the presence and possible nesting of Snowy Plovers. Geographic extent of the study area ranged east-west from Lake Coleman (Coleman County) to Imperial Reservoir (Pecos County) and north-south from Lake J.B. Thomas (Borden and Scurry counties) to Brady Reservoir (McCulloch County). In summer 1999, O.C. Fisher (Tom Green County) was surveyed on 8 May and visited five additional times during the summer to document nesting occurrence and success of Snowy Plovers and Interior Least Terns.

Each lake was surveyed on foot or by boat. Since Snowy Plovers require broad, extensive gravel, mud or sandflats or islands, lakes were first surveyed for the presence of appropriate potential habitat. Those with little or no flats or islands were not examined for plovers. When plovers were found, they were observed for behavioral indicators of nesting such as distraction behavior and territorial defense (Page et al. 1995). Observations were made from a distance to prevent disturbance of the birds. Birds were observed for approximately 20 minutes in order to locate possible nests. If a nest was suspected, the bird was approached to check for eggs.

Table 1. Summer occurrence of Snowy Plovers, Spotted Sandpipers, and Interior Least Terns in west-central Texas in 1998.

Lake ¹	County	Date	Habitat ²	Snowy Plover ³	Spotted Sandpiper ³	Interior Least Tern ³
Abilene	Taylor	5/31	M	0	? P	0
Ballinger (New)	Runnels	7/5	M	0	0	0
Ballinger (Old)	Runnels	7/5	NP	0	0	0
Brady	McCulloch	6/28	M	0	0	0
Champion Creek	Mitchell	6/12	M	0	0	0
Coleman	Coleman	5/31	NP	0	0	0
Colorado City	Mitchell	6/12	E	24 B	0	0 P
EV Spence	Coke	7/14	E	4 P	0	0 P
Hords Creek	Coleman	5/31	NP	0	0	0
Imperial	Pecos	7/19	E	36(2+) B	? P	26(?) B
JB Thomas	Borden, Scurry	6/12	E	0 P	0	0 P
OC Fisher	Tom Green	5/29	NP	0	? P	0
		7/28	NP	2		0
Oak Creek	Coke	5/31	NP	0	2(4) B	0
Twin Buttes	Tom Green	6/15	E	15 P	0	? P
		7/28	E	23(2) B	0	? P

¹ Nasworthy (Tom Green County) and O.H. Ivie Reservoirs (Concho County) were visited prior to the breeding season and lacked suitable habitat to warrant surveying.
² M=moderate, E=extensive, NP=not present.
³ Number adults (number juveniles or chicks), B=breeding, P=breeding possible based on presence of adults and/or suitable habitat, ?=present in unknown number.

Surveys for Interior Least Terns were conducted as described above for Snowy Plovers. Interior Least Terns have similar breeding habitat requirements to the Snowy Plover, and the two species are known to nest together (Grover & Knopf 1982; Thompson & Slack 1982; Rupert 1997; Thompson et al. 1997; this study). During another study in 2000-2002, Kasner (2004) recorded nesting occurrence of Interior Least Terns at sites in east-central and north Texas by field observation or personal communication with reliable observers. In addition to the sixteen lakes in Table 1, Fairfield Lake, in Freestone County, was surveyed 2000-2002, and Richland Chambers Reservoir, in Freestone and Navarro counties, was surveyed 2001-2002. Late May – July 2002, surveys were done throughout the Texas Panhandle (Canadian River, Prairie Dog

Town Fork of the Red River, Salt Fork of the Red River, North Fork of the Red River, and various reservoirs), on the Red River below Dennison Dam (Lake Texoma), west-central Texas in Tom Green (O.C. Fisher Reservoir and Twin Buttes Reservoir) and Pecos (Imperial Reservoir) counties, and in north-central Texas (Dallas County). When terns were found, they were observed for behavioral indicators of nesting such as distraction behavior, territorial defense, and courtship (Thompson et al. 1997).

Since Spotted Sandpipers are habitat generalists (Oring et al. 1997), their presence was observed while surveying lakes and streams for plover and tern habitat. In addition, unpublished nesting records from the Texas Breeding Bird Atlas Project (TBBAP) collected in the late 1980s and 1990s are included where new breeding records for the three species were recorded (Husak & Maxwell 2000). New breeding records are only reported here for the three species if nesting or presence of young was confirmed.

RESULTS AND DISCUSSION

Snowy Plover (*Charadrius alexandrinus*)

The Snowy Plover (*Charadrius alexandrinus*, Charadriiformes: Charadriidae) occurs throughout the year in Texas, wintering primarily along the Gulf Coast (Withers & Chapman 1993; Brush 1995) and breeding in both coastal and inland locations (Oberholser 1974; Withers & Chapman 1993; Davis 1996; Rupert 1997). Snowy Plover nesting habitat includes broad sandflats, sandy beaches, broad mudflats (Oberholser 1974; Myers 1984; Hayman et al. 1986; Withers & Chapman 1993; Brush 1995; Rupert 1997), and salt or alkaline flats at freshwater sites (Page et al. 1995; Koenen & Utych 1996). Subspecific status of the Snowy Plover is difficult, with conflicting records in the literature (Pulich 1988, Page et al. 1995). It is possible that those nesting in the interior of North America west of the Mississippi River are of the Western subspecies (*C. alexandrinus nivosus*), listed under Category 2 of the

Endangered Species Act (U.S. Fish and Wildlife Service 1991), although this possibility remains unexamined.

Oberholser (1974) reports nesting of Snowy Plovers as confirmed by specimens or presence of eggs in the interior of Texas in Wilbarger County, possible breeding in Glasscock, Midland, Howard, and Martin counties. Page et al. (1995) list similar interior breeding locations, adding north-central Texas. Seyffert (2001) reports breeding in Roberts and Childress counties in the Panhandle. Pulich (1988) reports nesting previously documented on the Pease River in Wilbarger County in 1929, but no nesting has been documented there since that time. White (2002) reports no nesting by the species in northeast Texas. Checklists of Texas Ornithological Society (1995) and American Ornithologists' Union (1998) list breeding range similar to Oberholser (1974) and Seyffert (2001) (Fig. 1).

1998 Breeding Season.—Nine of the sixteen lakes in the study area had sufficient habitat to warrant surveying for Snowy Plover (Table 1). A total of 104 birds were present at five of the nine lakes (Table 1). Territoriality was observed at four lakes where plovers were present.

On 28 July 1998, sufficient nesting habitat was unavailable at O.C. Fisher Reservoir, but two Snowy Plovers were present with no indication of nesting. Water level at Lake J.B. Thomas was extremely low and had extensive mudflats, making the presence of Snowy Plover very likely; however, inaccessibility due to low water conditions and private land prevented adequate surveying. The limited area surveyed yielded no plovers. Lake Colorado City had the most suitable habitat of all observed lakes. The lake was several meters low, exposing extensive sandflats. Due to inaccessibility, some of the sandflats could not be reached for surveying. Twenty-four birds (twelve male/female pairs) were counted. The actual number of birds present was estimated at 30 to 40 based on the amount of habitat present and the approximate territory size of the counted pairs. Twenty-four Snowy Plovers at Lake Colorado City were in distinct male/female pairs and exhibited spatial

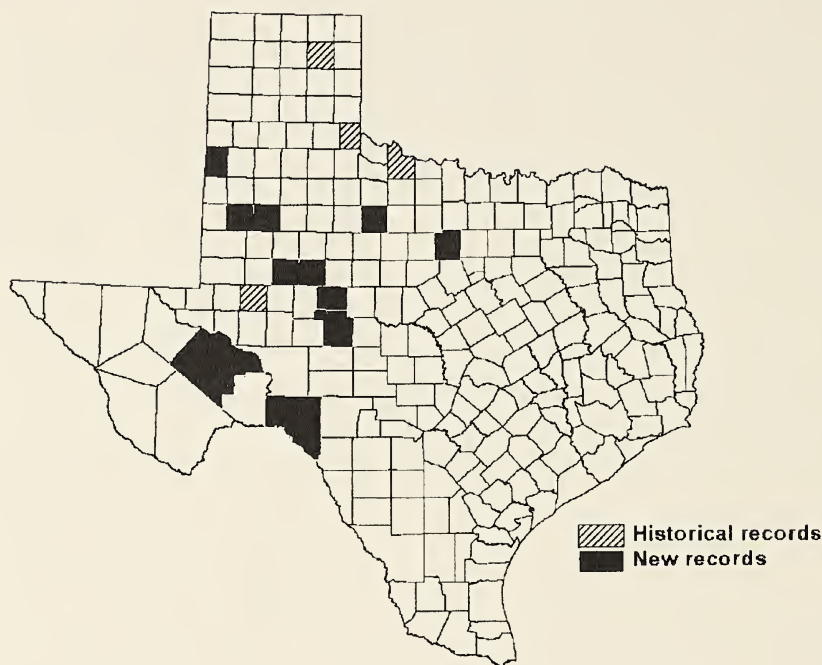


Figure 1. Historical and revised breeding distribution of the Snowy Plover (*Charadrius alexandrinus*) in the interior of Texas.

territorial defense like that of the breeding territoriality described by Myers et al. (1979). Distraction behavior was observed often, but no nests were found. Fifteen Snowy Plovers present at Twin Buttes Reservoir on 15 June 1998 were defending territories, and twenty-three Snowy Plovers present at Twin Buttes Reservoir on 28 July 1998 included two pairs with one juvenile each (Table 1). E.V. Spence Reservoir was also low and mostly inaccessible, with extensive mudflats present. Four plovers, two of each sex, were present in the area surveyed. No evidence of nesting was detected. Imperial Reservoir had 36 Snowy Plovers, including two juveniles with other possible juveniles present.

1999 Breeding Season.—O.C. Fisher Reservoir in Tom Green County was surveyed six times during the summer of 1999 to document nesting success of Snowy Plovers. Snowy Plovers nested successfully at O.C. Fisher Reservoir during the 1999 breeding season, confirming breeding by the species in Tom Green County. Rapidly falling water levels and a lack of spring runoff in the North Concho River watershed yielded broad mudflats and numerous exposed gravel islands in the reservoir. On 8 May 1999, 14 adult Snowy Plovers were present on mudflats at the reservoir. Vegetation had encroached on mudflats but had not covered gravel islands. All plover nesting at the reservoir in 1999 occurred on newly exposed gravel islands. Snowy Plovers nested in Interior Least Tern colonies, making positive identification of plover nests difficult. Six nests were presumed to be Snowy Plovers, with two of these confirmed by presence of brooding adults. The remaining nests were identified visually, noting egg shape and size (Harrison 1978). Cumulatively, six nests, five chicks, five fledglings, and one juvenile Snowy Plover were observed during visits to the reservoir. Numbers of chicks and juveniles are probably conservative due to difficulty in locating them once they have left the nest and given the likelihood that some nests on the reservoir went undetected.

It is likely that Snowy Plovers nest regularly in west-central Texas when conditions are favorable, given the amount of habitat and number of birds present at several reservoirs in the region (Table 1). Six lakes are categorized as possible nesting sites in Table 1 based on the presence of adult Snowy Plovers and/or adequate habitat to support breeding populations. Presence of juvenile Snowy Plovers at Imperial Reservoir in Pecos county and Twin Buttes Reservoir in Tom Green County indicates nesting at these reservoirs in 1998. This represents the first record for breeding Snowy Plovers in Pecos County (Fig. 1). The presence of distinct male/female pairs at Lake Colorado City and behavior indicative of breeding birds suggests that breeding occurred at the lake in 1998, representing the first breeding record for Snowy Plover in Mitchell County (Fig. 1). Breeding is confirmed for Tom Green County with birds breeding at Twin Buttes in 1998 and O.C.

Fisher in 1999 (Fig. 1). Lockwood (2001) reports that Snowy Plovers are known to nest on Amistad Reservoir (Val Verde County) when water levels are low enough to provide suitable habitat. Conway & Smith (2000) report nesting Snowy Plovers in Lynn, Terry, and Bailey counties. The above reported records in addition to unpublished nesting records from the TBBAP reporting new records for Howard and Midland counties (west Texas) and Palo Pinto, Bailey and Haskell counties (north-central Texas) show significant expansion of the breeding distribution of Snowy Plovers in west and north-central Texas (Fig. 1).

Spotted Sandpiper
(*Actitis macularia*)

The Spotted Sandpiper (*Actitis macularia*, Charadriiformes: Scolopacidae) breeds primarily in eastern North America, occasionally south to the extreme northern portions of the Gulf states (Oring et al. 1997). The species winters in the Gulf states, including Texas, with non-breeders present in Texas as late as May and as early as July. Oring et al. (1997) reported that it becomes scarce and very local near the southern edge of its breeding range. Oberholser (1974) reports the only definite breeding records in Texas, including one record in Deaf Smith County in 1920 (adult seen with young) and one record in Harris County in 1837 (broods of young seen by John J. Audubon). The species is present throughout the state in summer (Oberholser 1974), with possible breeding reported by Oberholser (1974) in Culberson, Kendall, Tom Green, and Travis counties and by Seyffert (2001) in Hutchinson, Gray, and Randall counties (Fig. 2). Recent nesting evidence is lacking (Seyffert 2001), despite the bird's persistent presence throughout the state in summer. Pulich (1988) and White (2002) report no evidence of nesting in north-central and northeast Texas. Checklists of the American Ornithologists' Union (1998) and Texas Ornithological Society (1995) report similar summer occurrence and possible nesting in central Texas.

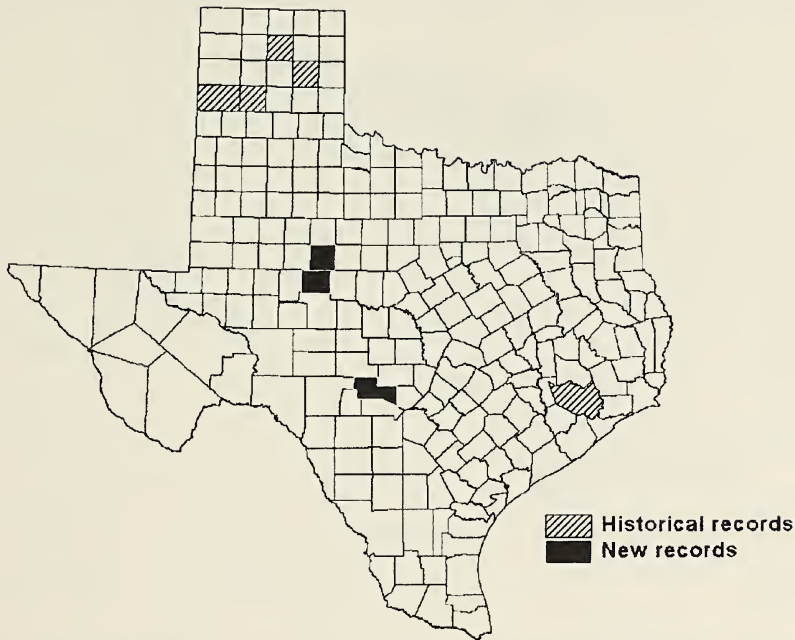


Figure 2. Historical and revised breeding distribution of the Spotted Sandpiper (*Actitis macularia*) in Texas.

Survey efforts during this study discovered only one breeding occurrence at Oak Creek Reservoir in Coke and Nolan counties in 1998. One pair of adult Spotted Sandpipers were observed with four young. This represents the first breeding record of Spotted Sandpiper for Coke and Nolan counties (observation was made near the county line, so both counties are included) and confirms breeding for the species in central Texas (Fig. 2). Although breeding was not confirmed elsewhere in the survey area, Spotted Sandpipers (potentially non-breeders) were observed at four of the lakes in the survey (Table 1). Lockwood (2001) reported two adult Spotted Sandpipers with “flying young” at the Kerrville sewage ponds in Kerr County in June 1988. Additional breeding occurrences in central Texas are possible, with unconfirmed reports from the TBBAP

for Menard and Kimble counties, expanding Spotted Sandpiper breeding distributions into the hill country of central Texas (Fig. 2).

Interior Least Tern
(*Sterna antillarum athalassos*)

Three subspecies of the Least Tern (*Sterna antillarum*) are currently recognized (U.S. Fish and Wildlife Service 1990; Thompson et al. 1997; American Ornithologists' Union 1998). The Interior Least Tern (*S. antillarum athalassos*) nests throughout the interior of North America in colonies typically smaller in size than coastal colonies (Downing 1980; Kress et al. 1983; Schulenberg & Ptacek 1984; Sidle et al. 1988). Interior Least Terns nest on open sand or salt flats and sand and gravel bars in rivers and reservoirs (Gochfeld 1983; Grover & Knopf 1982; Thompson et al. 1997; U.S. Fish and Wildlife Service 1990). The ephemerality of nesting sites and the destruction of suitable habitat by human encroachment and channel alteration have led to federal listing of the Interior Least Tern as endangered (U.S. Fish and Wildlife Service 1985; 1990).

Downing (1980) reports Interior Least Terns as breeding along the Red and Canadian rivers in north Texas. Oberholser (1974) reports confirmed breeding records for Wilbarger and Bowie counties. Seyffert (2001) reports breeding in Hutchinson, Roberts, and Hemphill counties along the Canadian River and in Briscoe, Hall, and Childress counties along the Prairie Dog Town Fork of the Red River (Conway et al. 2003). Breeding Interior Least Terns have also been reported in Grayson, Hardeman and Wichita counties along the Red River, in Val Verde County at Amistad Reservoir, Webb County on Lake Casa Blanca and gravel pits along the Rio Grande, and Zapata and Starr counties at Falcon Reservoir (Downing 1980; Pulich 1988; USFWS 1990; Kirsch & Sidle 1999; Lockwood 2001, T. Brush, pers. comm.). Pulich (1988) also reports nesting last reported in 1959 in Denton County and 1929 in Wilbarger County. The American Ornithologists' Union checklist (1998) and Texas Ornithological Society checklist (1995) list breeding ranges concurrent with those listed above (Fig. 3).

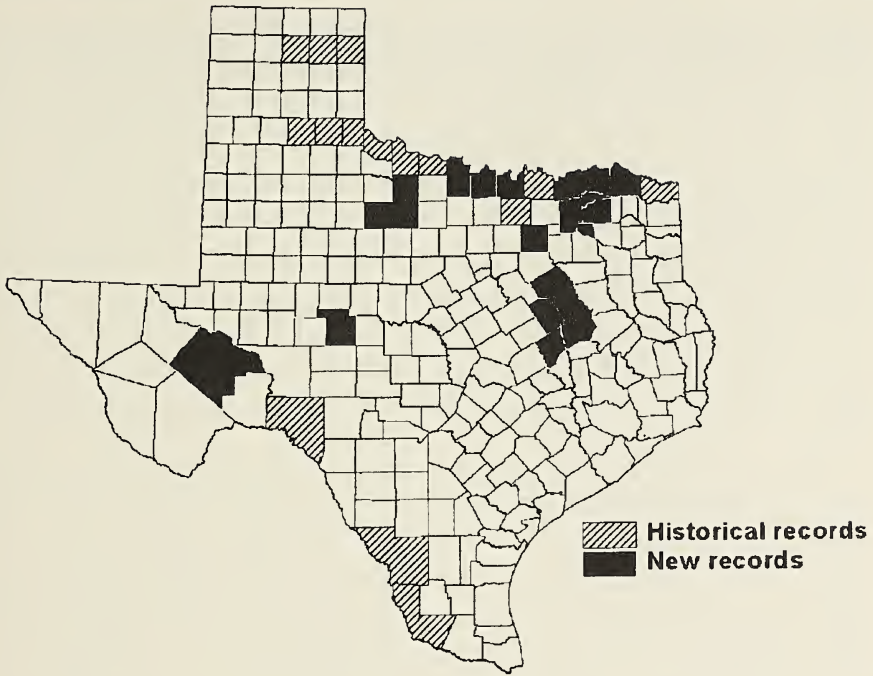


Figure 3. Historical and revised breeding distribution of the Interior Least Tern (*Sterna antillarum athalassos*) in Texas.

1998 breeding season.—Suitable habitat for nesting Interior Least Terns was found at nine lakes or reservoirs in 1998, coincidental with suitable habitat for Snowy Plovers (Table 1). In 1998, Interior Least Terns were observed at Twin Buttes Reservoir late in the summer. Breeding may have occurred at the lake, as suitable habitat was abundant, however terns were seen too late in the summer to determine whether they were breeding birds or early migrants. Twenty-six Interior Least Terns, including adults and juveniles, were seen at Imperial Reservoir (Pecos County) on 19 July 1998, indicating breeding by the species. This represents the first record of breeding by the species in Pecos County (Fig. 3).

1999 breeding season.—In 1999, Least Terns nested with Snowy Plovers on two gravel islands in O.C. Fisher Reservoir in Tom Green County, representing the first breeding record for Interior

Least Terns in Tom Green County and extending the breeding distribution of the species into west-central Texas (Fig. 3). Approximately 20 adult terns were observed throughout the summer. Nests were first detected on 15 June 1999. Tern chicks were first detected in early July, including five young chicks, one chick near fledging, and one juvenile. Terns were last seen on 14 August 1999, including eight adults and two juveniles. Cumulatively, approximately 20 adults, 10 nests, six chicks, and two juvenile terns were observed during the summer. Some of these nests probably were renest attempts. Some eggs were depredated, likely by Great Blue Herons (*Ardea herodias*) which visited the islands regularly.

2000-2002 breeding seasons.—Interior Least Terns were present at Fairfield Reservoir in Freestone County 2000-2004. Least Terns have nested on Big Brown Mine every year since 1997, less than 1 mile from the lake, averaging 25 nests per year and 11 fledglings per year (Kasner 2004; Tanner & Kasner 2004). This represents the first breeding record for Freestone County (Fig. 3). Terns have been observed at Limestone Reservoir (Limestone County), with breeding reported at a nearby coal mine (Leon County) in 2000 and 2001 (J.M. Tanner, pers. comm.), and on gravel operations in nearby Robertson County (K. Arnold, pers. comm.). These represent first breeding records for Limestone, Roberts, and Leon counties, extending the breeding distribution into central Texas (Fig. 3).

Interior Least Terns have also nested at the Dallas Southside Wastewater Treatment Facility and gravel operations in Dallas County since 1992 (Kirsch & Sidle 1999; D. Wilhelm USFWS, pers. comm.), representing the first breeding records for Dallas County (Fig. 3). White (2002) provides recent reports of breeding Least Terns on Tawakoni Reservoir (Rains and Hunt counties) and Cooper Reservoir (Delta and Hopkins counties). Unpublished records from the TBBAP (including data from USFWS airboat surveys of the Red River above Lake Texoma) include new Least Tern breeding records for Haskell, Baylor and Throckmorton counties (Millers Creek Reservoir and Lake Kemp) extending the

distribution in north-central Texas, and in Clay, Montague, Cooke, Lamar, Bowie, and Red River counties along the Red River in north Texas (Fig. 3).

Surveys in summer 2002 throughout most of the state yielded 14 Interior Least Tern colonies in 11 counties including Bowie, Fannin, and Red River counties (4 colonies on the Red River); Dallas County (wastewater facility, gravel quarry, and a gravel rooftop, Boylen et al. 2004); Freestone County (Big Brown Mine); Grayson County (Lake Texoma, Hagerman NWR); Pecos County (Imperial Reservoir); Tom Green County (Twin Buttes and O.C. Fisher Reservoirs), and Zapata and Starr counties (Falcon Reservoir) (Kasner 2004). Least Terns were recorded breeding for the first time at Richland-Chambers Reservoir (Freestone and Navarro counties), although nesting was suspected there in 2001. This, in addition to colonies in several counties reported as recent records above provide additional evidence that Interior Least Terns are expanding their range throughout the interior of Texas (Fig. 3).

CONCLUSIONS

This study, along with new reports in the TBBAP and other recent literature, presents significant expansions for the breeding ranges of Snowy Plover, Spotted Sandpiper, and Interior Least Tern in Texas. It is not certain whether Snowy Plovers have always bred in central and west Texas and gone undetected, or the species is expanding its breeding range. Snowy Plovers and Least Terns both tend to nest in newly formed ephemeral habitats often created by human disturbance of the landscape. The addition of reservoirs in west-central Texas in the last half-century has certainly created nesting habitat that was not present before for all three species. Spotted Sandpipers are habitat generalists and can nest along small streams, and such habitat is readily available throughout the state, however, evidence for expansion of the breeding range in Texas is limited. The species has likely nested in low numbers and gone undetected in west-central Texas, while non-breeders persist throughout the state as late as May and as early as July. Interior

Least Terns and Snowy Plovers are definitely expanding their breeding range into central and western portions of the state, taking advantage of new lakes, reservoirs, and industrial development such as surface coal mines, gravel quarries, and oil well pads. Most of the expansion by the Interior Least Tern has occurred at such human disturbed sites in east-central Texas or at reservoirs in west-central Texas. The potential for continued expansion by Interior Least Terns and Snowy Plovers exists throughout the state. More intensive survey efforts will likely yield further expansion of the known breeding range of all three species in Texas.

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GENERAL NOTES

NOTEWORTHY RECORDS OF MAMMALS HOUSED IN THE
STEPHEN F. AUSTIN STATE UNIVERSITY VERTEBRATE
NATURAL HISTORY COLLECTION**Sarah A. Johnson, Andy P. Bradstreet and Cody W. Edwards****Department of Biology, Stephen F. Austin State University
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The Collection of Mammals at the Stephen F. Austin State University Vertebrate Natural History Collection (SFA) was established in the early 1950s by W. H. McCarley and other faculty members of the Department of Biology. Over the next three decades, contributions by R. L. Packard, E. D. Michael and C. D. Fisher brought the collection close to its current size of more than 3,000 specimens. The collection remained without curation from the late 1970s until 2002. At this time, a project was undertaken to inventory and update the SFA. Similar examinations of vertebrate natural history collections by Revelez & Dowler (2001) from Angelo State University, Goetze & Nelson (2004) from Midwestern State University, and Goetz et al. (2004) from Tarleton State University have yielded previously undocumented county records for Texas mammals. This project resulted in the discovery of 17 previously unreported county records for 14 species. These new records represent seven of the 10 major ecological regions of Texas: Pineywoods, Post Oak Savannah, Blackland Prairies, Cross Timbers and Prairies, Edwards Plateau, Rolling Plains and the High Plains (Schmidly 2004).

Dasypus novemcinctus.—The nine-banded armadillo is absent only from the western Trans-Pecos of Texas (Schmidly 2004). Armadillos prefer areas with friable soils and tend to den near water. The armadillo has been steadily expanding northward from a nineteenth century range reaching only into extreme southern

Texas (Van Deelen et al. 2002). One male is reported from Smith County.

Material examined.—Smith County, Tyler (SFA 1617, 10 Oct. 1960, immature male).

Myotis velifer.—The cave myotis is distributed throughout much of western Texas with the exception of the westernmost and northernmost panhandle region (Schmidly 2004). The species is a colonial, cave-dwelling bat that is abundant throughout its range (Schmidly 1991). Two females were collected in Gillespie County.

Material examined.—Gillespie County, 6 mi. E of Fredericksburg (SFA 2359, 26 Nov. 1969, female); 6 mi. W of Stonewall (SFA 2380, 26 Nov. 1969, female).

Lasiurus borealis.—The eastern red bat is distributed statewide, but rare in the Trans-Pecos. These bats do not utilize caves or mine tunnels, but instead roost in the open in trees. They are permanent residents in the eastern portion of the state, and found only during the summer in the western portion of the state (Schmidly 2004). One male and one female were collected in Angelina County.

Material examined.—Angelina County, 5 mi. N of Lufkin (SFA 1715, 19 July 1967, male); 1 mile S of Lufkin (SFA 2585, 29 Nov. 1970, female).

Lasiurus cinereus.—The hoary bat is a state-wide migratory species in Texas. Like *L. borealis*, the hoary bat roosts mostly in the open in trees (Schmidly 2004). It is a spring-fall migrant. One hoary bat was collected in Fayette County.

Material examined.—Fayette County, La Grange (SFA 1474, no date, no gender data).

Pipistrellus subflavus.—The eastern pipistrelle occurs primarily throughout the eastern half of Texas including the Rolling Plains and central Texas (Schmidly 2004). However, relatively few specimens have been documented from the northeastern portion of its range in Texas. One male is reported from Rusk County.

Material examined.—Rusk County, 20 mi. N of Nacogdoches (SFA 3078, 3 Oct. 1974, male).

Tadarida brasiliensis.—The Brazilian free-tailed bat occurs throughout Texas during the summer months, but is found primarily in the eastern one-fourth of the state during winter months (Schmidly 2004). This colonial species selects caves along the Balcones Escarpment and Edwards Plateau where populations can reach 10 to 20 million bats during the summer (Schmidly 1991). Despite their presence in eastern Texas, Brazilian free-tailed bats have been documented in less than half the counties of the Pineywoods ecoregion. One male is reported from Shelby County.

Material examined.—Shelby County, 20 mi. S of Center (SFA 2921, 13 Oct. 1972, male).

Bassariscus astutus.—The ringtail has a statewide distribution pattern within Texas. However, they are more common in the Trans-Pecos, Edwards Plateau, and Cross Timbers regions, and less common in the woodland areas of east Texas (Schmidly 2004). Ringtails den in hollow trees, logs, brush piles, or rock caves (Schmidly 2004). One ringtail was collected in Parker County.

Material examined.—Parker County, 10 mi. W of Fort Worth (SFA 1439, 29 Dec. 1965, no gender data).

Sciurus carolinensis.—The eastern gray squirrel is found in the eastern one-third of the state, though it has been introduced at several locations west of its native range (Schmidly 2004). Two males are reported from Camp and Rusk counties.

Material examined.—Camp County, 5 mi. NW of Pittsburg (SFA 2291, 11 Nov. 1967, male). Rusk County, 5 mi. W of Laneville (SFA 2711, 3 Oct. 1965, male).

Glaucomys volans.—The eastern flying squirrel is distributed in wooded areas within the eastern third of the state. They den in hollow stumps, woodpecker nests, or construct nests out of Spanish moss (Schmidly 2004). One male is reported from San Augustine County.

Material examined.—San Augustine County, 2.5 mi. NW of San Augustine (SFA 1563, 10 July 1964, male).

Geomys breviceps.—Baird's pocket gopher occurs in the eastern portion of Texas, with its southwestern range being limited by the Brazos River (Schmidly 2004). This species is found throughout its range wherever areas of sandy or friable soil exist. Three males and five females are reported from Cherokee County.

Material examined.—Cherokee County, 0.5 mi. N of Maydell (SFA 107, 9 Apr. 1951, female); 2.5 mi. SW of Maydell (SFA 108, 25 Feb. 1951, female; SFA 111, 2 Mar. 1951, male; SFA 113, 24 Feb. 1951, female); 1.5 mi. N of Gallatin (SFA 462, 19 Nov. 1957, male); 3 mi. W of Forest (SFA 797, 7 July 1960, female); 6 mi. W of Alto (SFA 1223, 2 Dec. 1961, male; SFA 1227, 2 Dec. 1961, female).

Cratogeomys castanops.—The yellow-faced pocket gopher is found in the western third of the state, from the Panhandle S and along the Rio Grande. These gophers prefer sandy soils and usually are found where no *Geomys* occur (Schmidly 2004). Two males are reported from Crosby and Garza counties.

Material examined.—Crosby County, E of Crosbyton (SFA 2630, 20 Apr. 1963, male). Garza County, 9 mi. E of Southland (SFA 2629, 27 Apr. 1963, male).

Neotoma floridana.—The eastern woodrat is found throughout the eastern one-third of the state (Schmidly 2004). This species is most abundant within bottomland forests of eastern Texas, but is known to occupy a wide range of habitats. Two females were collected in Grayson County in northern Texas.

Material examined.—Grayson County, 4.4 mi. N of Sherman (SFA 2781, 21 Jan. 1965, female); Lake Texoma (SFA 2782, 15 Mar. 1965, female).

Sylvilagus floridanus.—The eastern cottontail has a statewide distribution but records are lacking from some counties (Schmidly 2004). Two females and one male are reported from Williamson County.

Material examined.—Williamson County, 8 mi. E of Granger (SFA 265, 25 Nov. 1949, female); 2 mi. SW of Georgetown (SFA 840, 23 Nov. 1959, male; SFA 841, 24 Nov. 1959, female).

Lepus californicus.—The black-tailed jackrabbit is distributed throughout most of Texas with the exception of the Big Thicket region of southeastern Texas. They inhabit arid regions with sparse vegetation (Schmidly 2004). The five specimens reported represent new records from Parker and Williamson counties.

Material examined.—Parker County, 10 mi. N of Ft. Worth (SFA 1520, 29 Dec. 1965, female; SFA 1840, 29 Dec. 1965, female); 12 mi. E of Weatherford (SFA 1548, 29 Dec. 1965, male; SFA 1549, 29 Dec. 1965, female). Williamson County, near Southwestern University (SFA 842, 24 Nov. 1959, no gender data).

Mustela frenata.—Except for the northern portion of the state, the long-tailed weasel is widely distributed throughout Texas. They are found in a variety of habitats, ranging from brush lands, to forests, to rocky deserts (Schmidly 2004). Several counties within Texas

lack records of their occurrence. One female is reported from Tyler County.

Materials examined.—Tyler County, 10 mi. W of Sperger (SFA 3160, 2 August 2004, female).

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REPRODUCTIVE CYCLE OF THE WESTERN SKINK,
EUMECES SKILTONIANUS (SAURIA: SCINCIDAE),
IN SOUTHERN CALIFORNIA

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The western skink, *Eumeces skiltonianus*, ranges from southern British Columbia to the tip of Baja California and occurs from sea level to 2,530 m (Stebbins 2003). Most of the information on *E. skiltonianus* reproduction is in Tanner (1943; 1957) who studied Utah specimens. Other information is in Van Denburgh (1922), Rodgers & Memmler (1943), Smith (1946), Stebbins (1954), Dixon (1967), Punzo (1982) and Fitch (1985). The biology of *E. skiltonianus* is summarized in Tanner (1988). The purpose of this paper is to provide information on the reproductive cycle of *E. skiltonianus* from southern California based on histological examination of gonadal materials from museum specimens and to compare the timing of the reproductive cycle with Utah as reported by Tanner (1943; 1957). This paper contains the first histological examination of the reproductive cycle in *E. skiltonianus*.

Fifty-two males (mean snout-vent length, SVL = 59.8 mm $\pm$ 6.4 SD, range = 49-78 mm), forty-one females (mean SVL = 63.1 mm $\pm$ 7.2 SD, range = 49-76 mm) and twelve juveniles (mean SVL = 24.7 mm $\pm$ 1.7 SD, range = 23-27 mm) *E. skiltonianus* from the Natural History Museum of Los Angeles County (LACM) and the San Diego Society of Natural History (SDSNH) were examined. *Eumeces skiltonianus* is most often observed from March to June (Stebbins 1954) which explains the small numbers of this species in collections from later in the year.

The left testis, epididymis and left ovary were removed from males and females, respectively. Gonads were embedded in paraffin, sectioned at 5 μ m, and stained with Harris' hematoxylin followed by eosin counterstain. All oviductal eggs or enlarged folli-

cles (> 4 mm length) were counted, but not examined histologically. Unpaired *t*-tests were performed to compare male and female mean body sizes, clutch sizes from southern California versus Utah, and mean body sizes of juveniles from spring versus summer-autumn. The relationship between female body size and clutch size was investigated by linear regression analysis.

Material examined.—The following specimens of *Eumeces skiltonianus* were examined by California County from the herpetology collections of the Natural History Museum of Los Angeles County (LACM) and the San Diego Society of Natural History (SDSNH). LOS ANGELES (LACM) 5945, 5946, 5953, 5955, 15012, 15015, 15025, 15041-15043, 15045, 15055, 15056, 15058, 15061, 15062, 15064, 15070, 52729, 62406, 62408, 99658, 99659, 137443, 150693-150696; RIVERSIDE (LACM) 15002, 15003, 22265, 73680, 74248, 76476, 99599, 99693, 99695, 99698, 99701-99703, 99705; ORANGE (LACM) 99664-99666, 99668, 99670-99674, 99680, 99681, 99685, 99687, 122080, 122081, 123416; SAN BERNARDINO (LACM) 5962, 14960, 14961, 14965, 14968, 14971, 14972, 14976-14978, 52723, 99428, 99706, 99707, 99710, 99711, 99715; SAN DIEGO (LACM) 5942, 27587, 52722, 52724, 52726, 99717, 99720, 99721, 99726, 99727, 99734, 99736, (SDSNH) 15984, 18716-18718; SANTA BARBARA (LACM) 99737, (SDSNH) 58125-58128, 58130-58133; VENTURA (LACM) 14982, 14984, 14987, 27595, 27596.

Testicular histology is similar to that reported for *Eumeces anthracinus pluvialis* and *Eumeces fasciatus* from Arkansas by Trauth (1994). Conditions in the seasonal testicular cycle are in Table 1. Sperm production (spermiogenesis) occurs in spring. In testes undergoing spermiogenesis, the inner border of the seminiferous tubules were lined by sperm. Layers of metamorphosing spermatids and primary spermatocytes were present. The outer layer of each seminiferous tubule contained mainly spermatogonia and Sertoli cells. Regressed testes were found (one each) in July and September. In regressed testes, seminiferous

Table 1. Conditions in seasonal testicular cycle of *Eumeces skiltonianus* from southern California. Values are the numbers of males exhibiting each of the three conditions.

Month	<i>n</i>	Regression	Recrudescent	Spermiogenesis
February	11	0	3	8
March	17	0	1	16
April	13	0	2	11
May	5	0	1	4
July	1	1	0	0
August	2	0	2	0
September	1	1	0	0
October	1	0	1	0
November	1	0	1	0

tubules were reduced in size. Germinal epithelium consisted mainly of spermatogonia and Sertoli cells. Recrudescence (testicular renewal) occurs mainly in summer and autumn. In recrudescence testes, there was a renewal of germinal epithelium in the seminiferous tubules. Primary spermatocytes were the predominant cell. Secondary spermatocytes and occasional spermatids were present in some males undergoing recrudescence. The epididymides of all testes undergoing spermiogenesis contained spermatozoa; those from lizards with regressed or recrudescence testes were empty. The smallest reproductively active male (spermiogenesis in progress) measured 49 mm SVL (LACM 27587) and was collected 24 March 1957. The time of *E. skiltonianus* mating in southern California is not known but, on the basis of males undergoing spermiogenesis (Table 1), it may occur as early as February. In Utah (various counties) mating occurs mainly in May (Tanner 1957). The presence of 8/11 (73%), 16/17 (94%) and 11/13 (85%) males undergoing spermiogenesis from February, March and April, respectively, suggests that mating begins earlier in southern California.

Females were significantly larger than males ($t = 2.4$, $df = 91$, $P = 0.02$) and were reproductively active from February-June (Tables 2, 3). Females undergoing early vitellogenesis (yolk deposition) were found December, February-April (Table 3). Clutch sizes are listed in Table 2. Mean clutch size for 10 females is 5.8 ± 2.3 SD,

Table 2. Stages in seasonal ovarian cycle of *Eumeces skiltonianus* from southern California. Values shown are the numbers of females exhibiting each of the four conditions.

Month	<i>n</i>	Inactive	Early yolk deposition	Moderate yolk deposition (follicles > 4 mm)	Oviductal eggs
February	4	2	2	0	0
March	14	3	7	3	1
April	7	0	3	4	0
May	2	0	0	2	0
June	1	0	0	1	0
July	3	3	0	0	0
August	1	1	0	0	0
September	4	4	0	0	0
October	4	4	0	0	0
December	1	0	1	0	0

Table 3. Clutch sizes for 10 *Eumeces skiltonianus* estimated from counts of yolked follicles > 4 mm length or oviductal eggs.

Date	SVL	Clutch size	Source
3 March 1957	54	5	LACM 99736
20 March 1960	68	7	LACM 99681
March 1987	73	10*	LACM 137443
11 April 1951	70	9	LACM 99665
12 April 1963	57	4	LACM 99698
18 April 1964	73	4	LACM 15064
28 April 1967	55	4	LACM 52726
12 May 1961	68	4	LACM 15043
May 1995	62	4	LACM 150696
2 June 1964	70	7	LACM 99659

* Oviductal eggs, all other females contained yolked follicles > 4 mm length.

range: 4-10. Eight clutches of *E. skiltonianus* eggs from Utah (Tanner 1957) averaged 4.0 ± 0.93 SD, range: 2-5. There was no significant difference between mean clutch size from southern California (reported herein) and Utah ($t = 2.1$, $df = 16$, $P = 0.05$). This is within the range of clutches (2-10) reported by Stebbins (2003). Punzo (1982) reported a mean of 4.7 (range 3-6) for 6 *E.*

skiltonianus clutches from San Bernardino County, California. Van Denburgh (1922) found a clutch of five eggs at Pacific Grove, Monterey County, California in mid-June. Stebbins (1954) reported that eggs are probably laid mainly in June in the vicinity of Berkeley, Alameda County, California with hatching occurring in July and August. In the northwestern United States, *E. skiltonianus* is thought to mate in May or June and deposit two to six eggs in June or July but definitive information is lacking (Brown et al. 1995). Samples are too small to ascertain geographic variation in clutch sizes for *E. skiltonianus* (Fitch 1985).

The relationship between female body size and clutch size for this study was not significant ($P = 0.09$) but the sample may have been too small for statistical analysis. The smallest reproductively active female (yolk deposition in progress) measured 52 mm SVL (LACM 52724) and was collected 25 March 1967. There was no suggestion (oviductal eggs with concurrent yolk deposition) in the same female to suggest more than one clutch of eggs is produced in the same reproductive season. Rodgers & Memmler (1943) reported that the smallest breeding *E. skiltonianus* from Contra Costa County, California measured 61-62 mm SVL. Tanner (1957) reported that the smallest gravid female from Utah measured 56 mm SVL. This is larger than the minimum sizes for reproduction (males 49 mm, females 52 mm SVL) reported herein.

Seven neonates were collected in July-September (mean SVL = $25.0 \text{ mm} \pm 2.0 \text{ SD}$, range = 23-27 mm). Rodgers & Memmler (1943) reported young *E. skiltonianus* hatched in July and August in Contra Costa County, California. In Utah, *E. skiltonianus* nests from early July until late August (Tanner 1943). Hatchlings were first observed 28-29 July in the San Bernardino Mountains, San Bernardino County, California and 3-13 August in Utah (Smith 1946) suggesting *E. skiltonianus* birth occurs later in Utah. There was no significant size difference ($t = 0.81$, $df = 10$, $P = 0.44$) between the seven July-September neonates and five juveniles collected from March and May (mean SVL = $24.2 \text{ mm} \pm 1.1 \text{ SD}$,

range = 23-25) suggesting limited growth for neonates before they enter hibernation. Rodgers & Memmler (1943) reported that *E. skiltonianus* measured 24.7 to 26.3 mm SVL at hatching. However, in contrast to findings in this study, they reported rapid growth for *E. skiltonianus* neonates with lizards measuring 37-43 mm by November. Adverse weather conditions such as drought which limit activity and feeding retard the growth of hatchlings (Tanner 1957).

The timing of the reproductive cycle of *E. skiltonianus* from southern California appears similar to that of other North American skinks such as *E. anthracinus* and *E. fasciatus* (Trauth 1994) which produce sperm during winter-spring. However, it markedly differs from that of *Eumeces egregius* which reproduces during autumn in Florida (Mount 1963).

In conclusion, timing of the reproductive cycle of *E. skiltonianus* appears similar in Utah and southern California with sperm formation and yolk deposition occurring mainly in spring. The onset of sperm formation is earlier in southern California, and the period of egg laying appears to end later in Utah. The first young are born earlier in southern California than in Utah. Female *E. skiltonianus* from southern California appear to reproduce at a smaller size than in Utah. Additional studies in different parts of its range will be needed to ascertain the amount of geographic variation in the reproductive cycle of *E. skiltonianus*.

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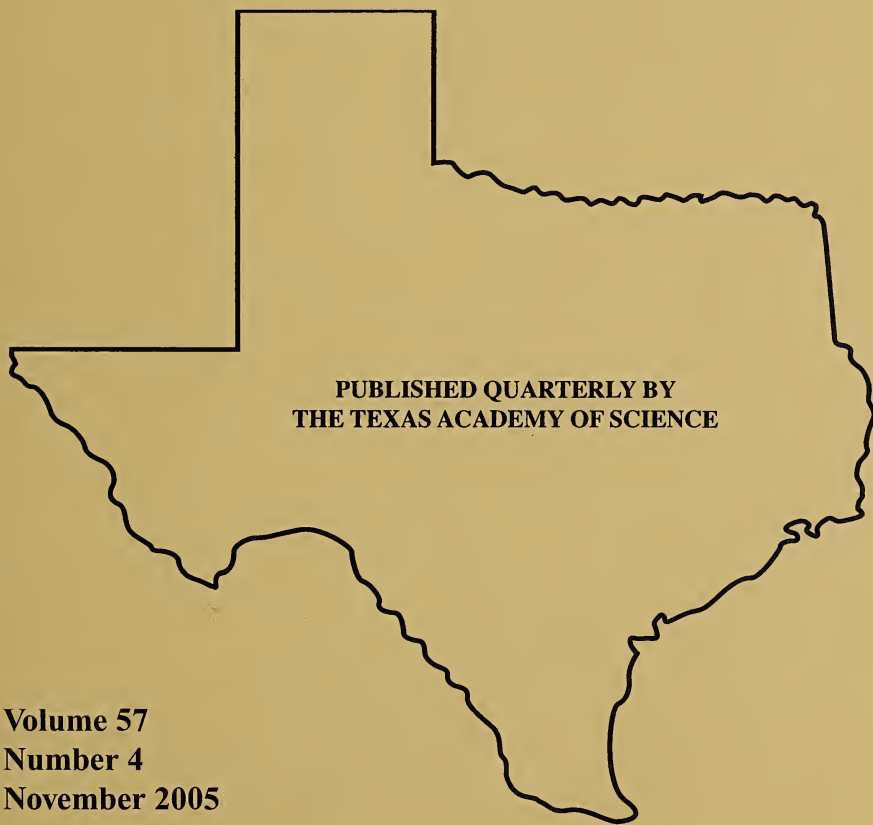
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NOTEWORTHY TURTLE REMAINS
FROM THE LATE MIOCENE (LATE HEMPHILLIAN)
OF NORTHEASTERN NEBRASKA

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Abstract.—Turtle fossils from the Late Miocene (Late Hemphillian NALMA) Devils Nest Airstrip site in Knox County, northeastern Nebraska, reconfirm the presence of *Emydoidea blandingii* and add *Trachemys* cf. *T. inflata* to the fauna. Both taxa are consistent with the suggestion that the turtle fauna of North America was essentially modern at the end of the Miocene. The presence of *Emydoidea blandingii* argues for the continued separation of *Emydoidea* and the Old World genus *Emys*, and the presence of *Trachemys* cf. *T. inflata* extends the paleogeographic record of the taxon to northeastern Nebraska.

The Devils Nest Airstrip site in Knox County, northeastern Nebraska, represents the latest part of the Hemphillian North American Land Mammal Age (NALMA) and dates about 5 Ma (Boelstorff 1976; Lindsay et al. 1976; Woodburne 1987; Voorhies 1988; Parmley 1992). Among the fossil amphibians and reptiles, the following turtle species were identified by Parmley (1992): *Apalone* sp., *Emydoidea blandingii*, *Chrysemys picta*, *Terrapene* sp., *Macrolemys temminckii*, and *Hesperotestudo* sp. The appearance of an essentially modern turtle fauna at the end of the Miocene in Nebraska is of great interest and has been confirmed at other fossil sites in Nebraska (Voorhies 1990), as well as a site in Indiana (Farlow et al. 2001), and at several sites in Florida (Hulbert 2001).

The discovery of additional material confirms the previous identification of *Emydoidea blandingii* (a much discussed extant species) from the Devils Nest Airstrip fauna (Parmley 1992). In addition, *Trachemys* cf. *T. inflata* is identified in the Nebraska fauna. This taxon is previously known only from Florida and Tennessee. It was described from Florida as *T. inflata* by Weaver & Robertson (1967) and recently discussed and figured by Hulbert

(2001). Abundant material identified as *Trachemys* cf. *T. inflata* from Tennessee has recently been detailed by Parmalee et al. (2002).

STUDY SITE

The Devils Nest Airstrip (University of Nebraska State Museum site Kx 113) lies in Knox County, NE Nebraska. This airstrip is a 1.5 km long, NNW trending dirt strip with its north end near the center of SE 1/4, NW 1/4, sec. 24, T33N, R4W and its south end at the center of SW1/4, NE 1/4, SE 1/4, sec. 24, T33N, R4W (Voorhies 1988). Fossil-bearing sediments were exposed in weathered channels along both sides of the strip and most of the fossils were obtained by surface collecting from these channels, often after rainstorms exposed new material. The Late Hemphillian age of 5.0 Ma for the airstrip site is mainly based on its stratigraphic and mammalian correlation with the nearby Santee local fauna (Voorhies 1988; Parmley 1992).

SYSTEMATIC PALEONTOLOGY

Generic and specific names follow Crother (2000) and Crother et. al. (2003). King & Burke (1997) is followed for higher taxonomic designations. Terminology of shell elements follows Holman (1995a). The fossils reported here either reside in the University of Nebraska State Museum (UNSM) or the Michigan State University Museum (MSUVP).

Class Reptilia Laurenti 1769

Order Testudines Batsch 1788

Family Emydidae Lydekker 1889

Genus *Emydoidea* Gray 1870

Emydoidea blandingii (Holbrook 1838)

Material examined.—One nuchal, UNSM 117936: one right hyoplastron and one left xiphoplastron UNSM 56911.

Remarks.—A fossil hyoplastron and xiphiplastron of *Emydoidea blandingii* was first reported from the Devils Nest Airport site by Parmley (1992). The fossil hyoplastron (Fig. 1b,c) has the following diagnostic characters of *Emydoidea blandingii*. The pectoral-abdominal sulcus joins the hyo-hyoplastral suture at the midline. The humeral-pectoral sulcus occurs far anteriorly. The epihyoplastral suture is angular. The bridge buttress is subdued. The posterior edge of the bone lateral to the bridge buttress is beveled for the hyoplastral hinge attachment. The fossil xiphiplastron (Fig. 1d,e) is assigned to *Emydoidea blandingii* on the basis of having a relatively short, broad femoral lip, a longer, narrower anal lip, and a deeply excavated abdominal oblique muscle scar on its dorsal surface (Preston & McCoy 1971). Both of these fossil elements represent individuals that are quite large compared to recent individuals (Parmley 1992).

An *Emydoidea blandingii* nuchal bone (Fig. 1a) was recently identified by JAH from the Devils Nest Airport Site. This nuchal represents an animal of similar size to that of the plastral bones above. The nuchal bone is elongated with a very long, narrow cervical scute that distinguishes modern *Emydoidea blandingii* from other modern North American emydid species. It may be distinguished from the Miocene (Barstovian NALMA) species *Emydoidea hutchisoni* Holman 1995a, presently represented only by nuchal bones (Holman 2002), in being larger and having a longer, narrower cervical scute.

Comment.—The first *Emydoidea* remains are known from two Miocene Late Barstovian NALMA (about 12 Ma) fossil quarries in Cherry County, Nebraska. Hutchison (1981) assigned his material to *Emydoidea* sp. Later, Holman (1995a) described *Emydoidea hutchisoni* on the basis of remains from the West Valentine Quarry (UNSM Cr 114), then later restricted the material this taxon is based upon to the nuchal bones reported by Holman (1995a; 2002). The holotype of *E. hutchisoni* remains a nuchal bone (UNSM 76200) from CR 114 (Holman 1995a:549 Fig. 1). The status of *E.*

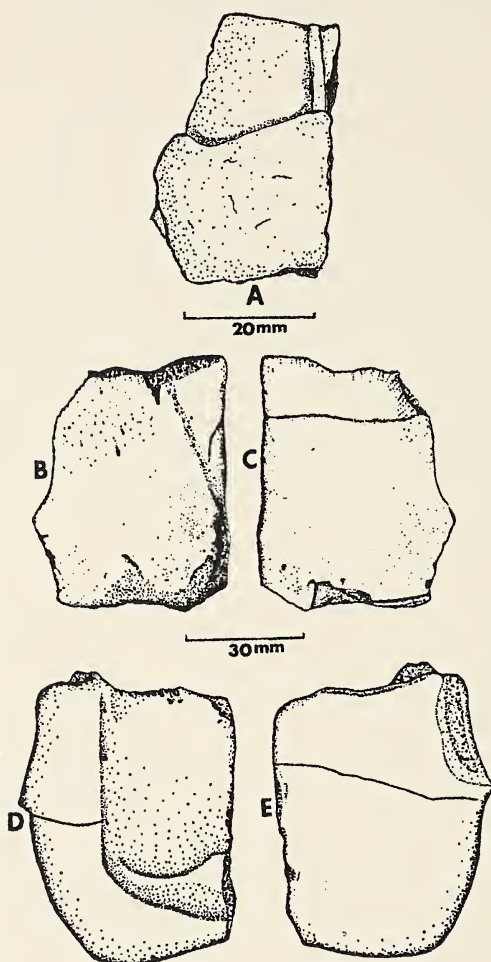


Figure 1. Devils Nest *Emydoidea blandingii* nuchal (a; UNSM 117936); right hyoplastron (UNSM 56911) in dorsal (b) and ventral (c) views; and left xiphiplastron (UNSM 56911) in dorsal (d) and ventral (e) views.

hutchisoni is now somewhat uncertain pending the discovery of new material.

The only other known pre-Pleistocene remains of *Emydoidea* is *Emydoidea* cf. *Emydoidea blandingii* from the Pipe Creek Sinkhole Biota Late Hemphillian site of Grant County, Indiana (Farlow et al.

2001). This identification is mainly based on fused xiphiplastra and a partial skull (Farlow et al. 2001:371 Fig. 3). *Emydoidea blandingii* has been reported from several Pleistocene sites, including extralimital records from Oklahoma (Preston & McCoy 1971; Holman 1995b), Mississippi (Jackson & Kaye 1974; Holman 1995b), and South Carolina (Bentley & Knight 1988). Presently, the modern species *Emydoidea blandingii* is the subject of much discussion, as some would combine this taxon with the Old World genus *Emys* (see Parham & Feldman 2002). The long separation of *Emydoidea* in time and space from *Emys* as well as the derived specializations of *Emydoidea* would argue for the continued recognition of the later generic name for *E. blandingii*.

Genus *Trachemys* Agassiz 1857

Trachemys cf. *Trachemys inflata* (Weaver & Robertson 1967)

Material examined.—One nuchal, UNSM 56909; left epiplastron, MSUVP 833; right epiplastron, MSUVP 868; right xiphiplastron, MSUVP 831.

Remarks.—The nuchal (Fig. 2a) appears almost identical to *Trachemys inflata* (Weaver & Robertson 1967 [see Weaver & Robertson 1967:57 Fig. 3; Hulbert 2001:128 Fig. 6.17h]), a common Late Miocene and Early Pliocene species in Florida. In fact, this species is the most common emydid of the extensive Bone Valley Palmetto Fauna of that state (Hulbert 2001). It also seems identical to the nuchal of *Trachemys* cf. *T. inflata* of the Late Miocene-Early Pliocene (cf. Hemphillian) Gray Fauna of Washington County in upper Eastern Tennessee (Parmalee et al. 2002: 236 Fig. 1b).

Important characters of the nuchal of this species include (1) nuchal thickened, (2) dorsal sculpturing prominent, (3) anterior border of nuchal deeply notched, (4) cervical scute area upraised, deep notches between it and adjacent peripheral bones, often with a terminal notch (see Hulbert 2001:128 Fig. 6.17h), and (5) peripheral bones pointed anteriorly. The Nebraska nuchal, UNSM 56909,

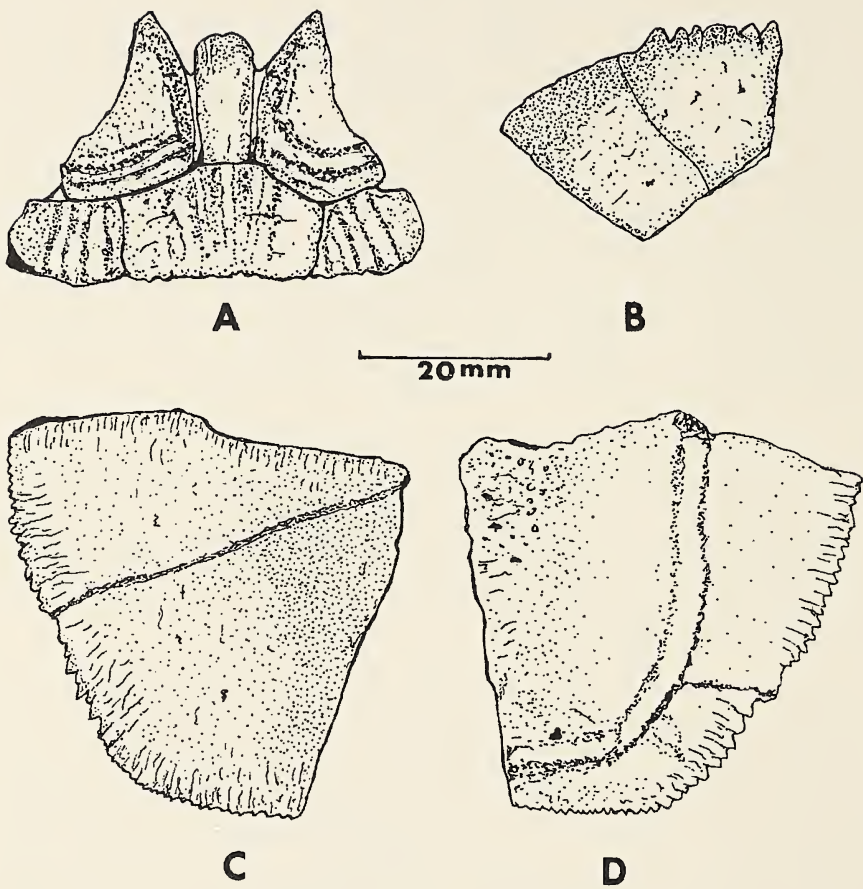


Figure 2. Devils Nest *Trachemys* cf. *T. inflata* nuchal (a; UNSM 56909); left epi-plastron (b; MSUVP 833), and right xiphiplastron (MSUVP 831) in ventral (c) and dorsal (d) views.

has all of these characters including the terminal notch in the upraised peripheral area (Fig. 2a). The Nebraska fossil (Fig.2a) is broken off posteriorly at about the posterior one-third of the first vertebral scute area.



Figure 3. Late Miocene-Early Pliocene paleodistribution of *Trachemys inflata*: closed circles represent previous records; star represents cf. allocation discussed here (see text).

In the holotype nuchal of *Trachemys inflata* from Palmetto, Polk County, Florida (see Weaver & Robertson 1967:57 Fig. 3; also see *T. inflata nuchal* from Nichols Mine, Polk County, Florida; Hulbert 2001:128 Fig. 6.17h), the bone under each scute area is highly inflated, producing considerably recessed sulci. In the Tennessee Gray Site nuchal specimens, these areas are thickened, but not as inflated as the Florida *T. inflata* specimens. Nevertheless, Parmalee et al. (2002) suggested that it is possible that this condition may vary with sex and/or age. The Devils Nest Airstrip nuchal is similar in this character with the Tennessee nuchals, this material is designated as *Trachemys* cf. *T. inflata*.

The two epiplastra (Fig. 2b) have serrated anterior margins as in *Trachemys* cf. *T. inflata* from the Gray Site in Tennessee, but the gular scute areas of the bones are not as extruded. This may be a sexually dimorphic character in *T. inflata*. The right xiphiplastron (Fig. 2c, d) also has its outer margin serrated as in the *Trachemys* cf. *T. inflata* xiphiplastra from Tennessee, but the shape of its posterior end does not indicate a posterior plastral notch as in the Tennessee plastron (see Parmalee et al. 2002:237 Fig. 2c & d).

CONCLUSIONS

This record of *Trachemys* cf. *T. inflata* extends the paleogeographic record of this Late Miocene- Early Pliocene taxon from Florida and upper northeastern Tennessee to northeastern Nebraska and indicates a rather wide range for this early *Trachemys* (Fig. 3). *Trachemys* cf. *T. scripta* has been identified from the Late Hemphillian Pipe Creek Sinkhole Biota in northeastern Indiana (Farlow et al. 2001), but additional material is needed to support full and confident assignment to species. Unfortunately, nuchal bones of this turtle have not yet been recovered from the site.

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DEFINITIVE LOCATIONS OF PALEOCENE AND EOCENE
MARINE FOSSIL LOCALITIES, COLORADO RIVER,
BASTROP COUNTY, TEXAS

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Abstract.—Outcrops of marine fossil-bearing Paleocene (Midway) and Eocene (Claiborne) strata located along the Colorado River in Bastrop County, Texas have been studied since the late 19th Century. These include type localities of many fossil species. Conflicting information is reported in the literature regarding some localities although much confusion has arisen from an incomplete knowledge of the geology and history of the Colorado River. This report locates the Tertiary marine fossil localities precisely and accurately, relating them to the original collections and their stratigraphic significance.

Angelo Heilprin published *The Eocene Mollusca of the State of Texas* (1891) based in part on the collections of T. A. Conrad and W. M. Gabb, but also material collected by geologists E. T. Dumble and R. A. F. Penrose, Jr. during a reconnaissance of the Colorado River in 1889. Of the localities he listed, there are four in Bastrop County: Camp Disaster, Bombshell Bluff, Devil's Eye, and Smithville, all at points along the Colorado River. The Dumble Collection at the Texas Memorial Museum includes material from these and additional Colorado River localities: David Bottom, Alum Creek Bluff, and Shipp's Ford. These are among the type localities for many Paleocene and Eocene mollusks, including several described by Aldrich (1911) and Harris (1919). The general stratigraphy of the lower Tertiary formations is shown in Figure 1.

The 1889 trip down the Colorado River was made in April of that year, between the dates of 6 April (the initial date in Penrose's field book) and 27 April (the date of a letter to his father relating the trip; Fairbanks & Berkeley 1952). The Colorado was a natural river then, but today it is regulated by a series of dams. Low water conditions such as experienced during the 1889 trip are now

Series		Stage	Formation	
Eocene	Middle	Claiborne	Yegua	
			Cook Mountain	← 17
				← 16
			Sparta	
			Weches	← 15
	Queen City		← 14 ← 13 ← 12	
	Lower		Reklaw	← 7, 8, 9, 10, 11 ← 6
Carrizo		← 5		
Paleocene	Sabine		← 4	
		Wilcox Group		
	Midway	Wills Point	← 3 ← 2 ← 1	
		Kincaid		

Figure 1. Generalized stratigraphic column of lower Tertiary deposits exposed along the Colorado River, Bastrop County, Texas (modified from Fisher, et al., 1964), with locality numbers from this paper.

restricted to the months between November and February. Many of the fossiliferous outcrops are only exposed during the very lowest stages of the river. A number of trips were made by boat over a three-year period, during all seasons, overlapping and repeating

sections of the river along its entire length in Bastrop County. For the most part, the descriptions of the river and its outcrops given in Penrose's original field notes (in the Texas Memorial Museum collections) are recognizable today, although the absolute distances given between locations were inaccurate. For this reason, the accurate location of the outcrops required that they be examined sequentially, i.e., following the same route and order as the original trip.

A consistent orientation is followed during this study when describing locations along the river, always from the point of view of a boat facing downstream. All distances are measured along the river. Points above are upstream, points below are downstream. The different banks of the river are referenced by left or right. Confusion arises when banks are referenced by compass direction, as can be seen in Figure 2, where the left bank of the river at Pope Bend is first the north side, then the south.

DISCUSSION

There is a nearly continuous exposure of Midway (Kincaid/Wills Point Formations) sandstone and shale along the right bank of the Colorado River starting about 3 km below Travis-Bastrop County line and continuing to the mouth of Dry Creek. At the upstream end of the section, hard, very fossiliferous glauconitic sandstone forms a shoal across the channel (Locality 1). The sandstone contains nautiloids and abundant other mollusks. The middle section is a very fossiliferous, glauconitic fine sand and clay, with the clam *Venericardia bulla*, many articulated and in life position (Locality 2). The downstream section is a fossiliferous, thinly bedded silty, glauconitic fossiliferous clay, containing a zone of concretions, some fossiliferous, near the top (Locality 3).

Deussen's (1924) Colorado River localities 213 and 214 (Figure 2a) correspond to this section, the first outcrops on the river of fossiliferous marine shale of Tertiary age. Gardner (1933:65) noted: "The section of the Midway along the Colorado River,

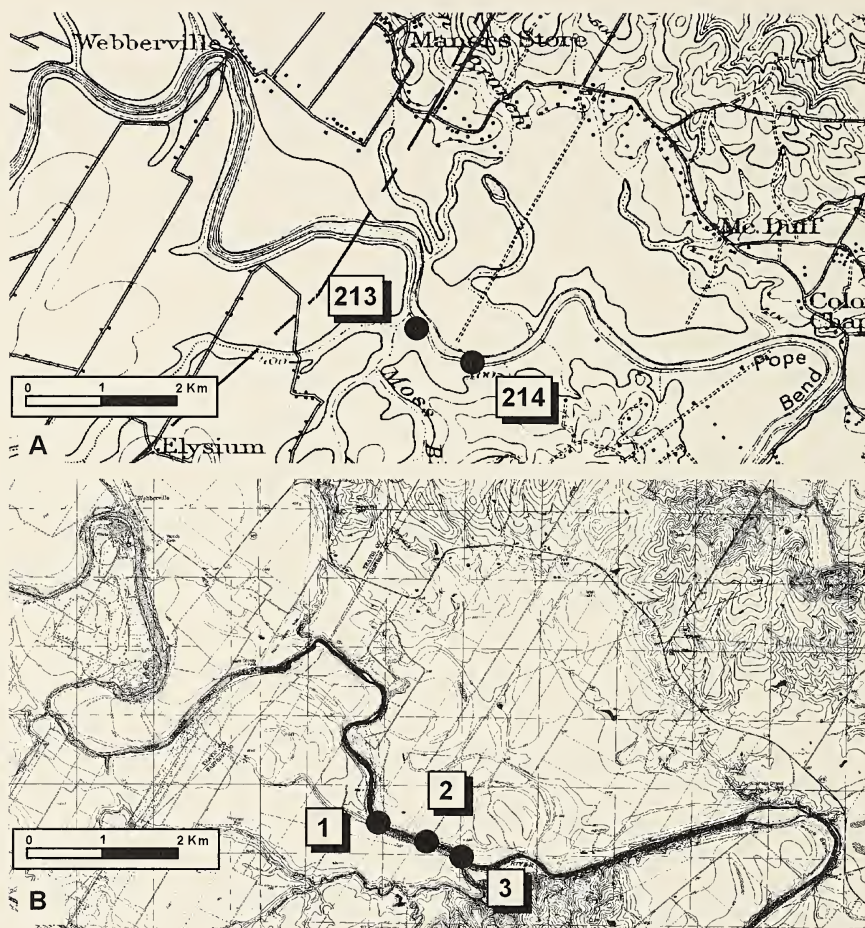


Figure 2. (2a) USGS Topographic map, 1904 (Original scale 1:100,000), of Colorado River just below Webberville, with Deussen's (1924) localities marked. (2b) USGS Topographic map, 1982 (Original scale 1:24,000), of the same area, with locality numbers from this paper.

though incomplete, is an exceptionally fine collecting ground." Her fossil localities 11890, 11913 - 11915, and 12111 - 12113 (Gardner 1933:106-108) were located on this same stretch of river between Localities 1 and 3 of this study. Penrose (1889) described these deposits: "On south side of river is a low bluff of greensand from 1-4 ft above the water and about $\frac{1}{4}$ mile long and full of shells..."

He named this location Camp Disaster, with no further explanation, and this is the locality thus noted by Heilprin (1891). Only Locality 2 of this study and Deussen's locality 214 correspond to Camp Disaster.

Below the mouth of Dry Creek and for the next 60 km of river there are no Tertiary marine outcrops, although there are many excellent exposures of Wilcox and Carrizo formations. The exposure of upper Wilcox and Carrizo at Red Bluff (Locality 4, not shown in figures) is most notable. McKinstry (1840) called it Iron Banks, but from Penrose (1889) onward it has been called Red Bluffs, because of the rust red staining of the conglomerate topping the bluff. Deussen (1924; pl. XVII) included a photograph of the bluff (his Locality 251). It is now much more overgrown but still easily accessible.

About 20 km downstream from Bastrop, Cedar Creek enters the river from the right side (Locality 5). This is a key location used in unraveling the confusion of the fossiliferous exposures downstream and was noted as a waypoint by McKinstry (1840) and Penrose (1889). The right bank of the Colorado River just below the mouth of Cedar Creek is a bluff about 12 m high, consisting mostly of cross-bedded sandstone (Carrizo Formation), capped by Pleistocene (?) conglomerate. Penrose (1889) described it as "At the mouth of Cedar Creek ... gray sands in cross-bedded beds, streaked in places with iron [oxide] and spotted with blotches of iron [oxide], even where it is not in contact with the heavy red Quaternary conglomerate". A few hundred meters downstream, below the mouth of Little Piney Creek, the glauconitic sandstone of the lower portion of the Reklaw Formation (Newby member) is exposed in the right bank of the river (Locality 6). These two locations correspond to Deussen's (1924) locality 253 and 254, respectively.

At a large southward bend of the Colorado River, a bluff about 300 m long, 3-5 m in height (Locality 7), exposes fossiliferous glauconitic sandstone and clay (the upper portion or Marquez

member of the Reklaw Formation), with spherical masses of iron sulfide 5-8 cm in diameter (“bombshells”). This section is capped with 1-2 m of conglomerate and river silt. It corresponds to Deussen’s (1924) locality 255, and is recognizable as Penrose’s Bombshell Bluff, which he placed 2 miles (3.2 km) below Cedar Creek on the north (actually east or left) side of the river. Penrose (1890) described Bombshell Bluff as “... the first fossil-bearing stratum seen since leaving Travis County”. Although this obviously neglects the Paleocene section at “Camp Disaster”, it definitively locates this outcrop, since this is indeed the first exposure below Cedar Creek to contain marine invertebrate fossils.

The 1904 Smithville Sheet topographic map (Figure 3a) labeled the area north of the Colorado River between the mouth of Cedar Creek and Bombshell Bluff as David Bottom. David Bottom was one of the five communities settled around 1828 by seven Missouri families under the original Stephen F. Austin grant, along with Alum Creek, Cottletown, Craft’s Prairie, and Flag Pond. The origin of the name David Bottom is probably derived from one of the original landholders in the area. McKinstry (1840) noted “David Holdeman’s [sic] landing” on the left side of the Colorado River, just above the mouth of Walnut (now Cedar) Creek. Kesselus (1999) quoted sources of original land titles that showed that David Holderman owned 500 acres on the Colorado River, 1200 varas (about a kilometer) wide, in this area. The original David Bottom was apparently located as shown on the 1904 map. In all likelihood, any fossil collections made before about 1930 and attributed to David Bottom came from Bombshell Bluff (Locality 7 of this report).

Garvie (1996) described a bluff (his locality 8) on the right bank of the river, currently about 60 meters back from the river, but evidently directly on the river in the late 1800s. He equated this bluff with Bombshell Bluff, but this is almost certainly Penrose’s (1889) McDonald’s Bluff. Downstream, a tall bluff (Locality 8), about 20 m in height, is exposed directly on the right bank of the

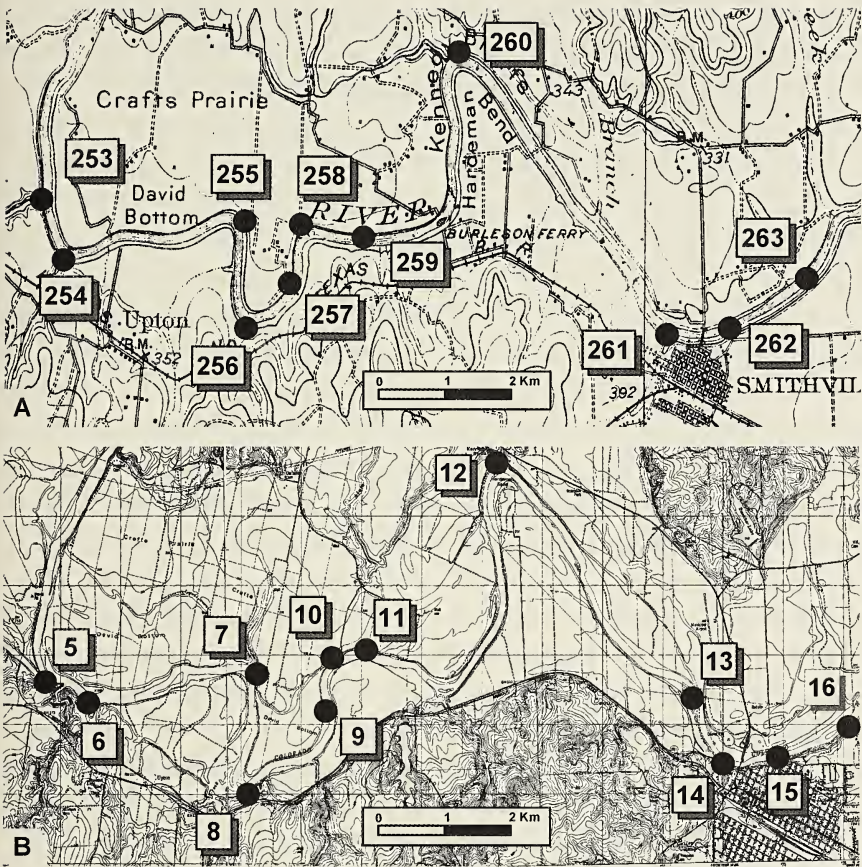


Figure 3. (3a) USGS Topographic map, 1904 (Original scale 1:100,000), of Colorado River above Smithville, with Deussen's (1924) localities marked. (3b) USGS Topographic map, 1982 (Original scale 1:24,000), of the same area, with locality numbers from this paper.

river, and can be recognized from Penrose's (1889) description (although the distance he reported is about twice the actual): "One half mile below this [McDonald's Bluff] and on the same side of the river is a ledge about 50 ft high of chocolate clays and sands and also gray sands, interbedded and interlaminated, also beds of semi-indurated greensand". This corresponds to Deussen's (1924) locality 256.

Penrose (1889) described Devil's Eye as 2 miles (3.2 km) below McDonald's Bluff at "an eddy made at a small peninsula of the same formation as the next bluff below McDonald's." Devil's Eye is perhaps the least certain of all the localities on the river. Deussen (1924) never mentioned Devil's Eye by name, but Plummer (1932) noted that "The first fossils from the Reklaw were named by Heilprin (1891) from a collection of fossils sent him by R. A. F. Penrose, Jr., collected from Devil's Eye, a shoal in Colorado River". Fisher, et al. (1964) described Devil's Eye as an "island in Colorado River", and Garvie (1996) as "former island in Colorado River". Although Penrose (1890) described Devil's Eye as "a low ledge", in his field notes (Penrose, 1889) his description was "shell bed ... 6-12 inches thick ... 6 feet above water", which matches the exposure found at small bluff on the left bank at an eastward bend of the river (Locality 10), and which corresponds to Deussen's (1924) locality 258. Penrose (1889) located it downstream of "indurated greensand in the river – small shoal – dip horizontal", which is descriptive of a small falls across the river formed by a bed of indurated glauconitic sandstone (Locality 9). McKinstry (1840) described an island "three fourths mile in length" near this same location named Devil's Towhead. A "towhead" is a sandbar in a river, especially one with a stand of cottonwood trees. Remnants of this "towhead" still exist upstream of the falls, corresponding roughly with Deussen's (1924) locality 257. The falls themselves are evident on aerial photographs dating back at least as far as 1951. A short distance below Locality 10, on the left bank, a small anticlinal fold exposes a thin sandstone ledge underlain by gray, fossiliferous clay (Locality 11). Penrose (1889) described a shell bed dipping 3° south, downstream of Devil's Eye, which probably corresponds to this location, and is likely Deussen's (1924) locality 259.

For the next several kilometers the Colorado River passes exposures of the Queen City Formation that lack marine fossils. At the mouth of Alum Creek, a striking exposure of the Queen City Formation towers above the left side of the river (Locality 12). Penrose described Alum Bluff (1889), or Alum Creek Bluff (1890),

as a bluff 40 feet (12 m) high, with a shell bed underlain by 20 feet (6 m) of cross-bedded sand. Vaughan (1900) described several corals that he attributed to Alum Bluff, and there are marine fossils in the Texas Memorial Museum collections attributed to Alum Bluff. However, Deussen (1924) described the same section, using the name Kennedy Bluff (his locality 260), as “beds of yellow sand and black shale of non-marine origin” and included a sketch of the bluff that matches the current exposure. Recent investigations have not found any marine fossils at this location, and the shale section appears to be non-marine – containing lignite and plant fossils. Callender (1958) divided the Queen City Formation in the area into three sections: a lower sand, partly marine at the base, a middle non-marine shale of probable deltaic origin, and an upper sand becoming marine near the top. It appears doubtful that marine fossils occur at this location, which exposes primarily the middle section of the formation. However, about 1.5 km upstream from the State Highway 96 bridge at Smithville, on the left side of the river (Locality 13), a bed of glauconitic sandstone containing moderately well-preserved mollusks, corals and shark teeth is exposed. The bed is overlain by several meters of typical, cross-bedded sandstone of the Queen City Formation, and indicates that isolated lenses of fossiliferous marine sediment occur within the formation. At the mouth of Gazley Creek, about 100 m upstream from the bridge at Smithville, about 1.5 m of uncemented, very fossiliferous quartz sand at the top of the Queen City Formation is exposed (Locality 14). This is the locality described by Price & Palmer (1928) and probably corresponds to Deussen’s (1924) locality 261.

A very fossiliferous sandstone ledge with abundant oysters and other mollusks is exposed in the riverbed about 100 m downstream from the Highway 96 bridge at Smithville (Locality 15). On the right bank of the river is the classic Smithville exposure of the Weches Formation (see Plummer 1932:640), Deussen’s (1924) locality 262, now landscaped residential riverfront property and no longer accessible for collecting. Several hundred meters downriver

Table 1. Colorado River localities referenced in text. Coordinates are given in meters, Universal Transverse Mercator projection (UTM Zone 14, NAD83), and decimal degrees west longitude and north latitude (NAD83). Localities marked with (*) are not shown on accompanying maps.

Locality Number	Historic Name	Formation(s)	Easting	Northing	Longitude	Latitude
1	—	Kincaid	645800	3340766	97.48549737	30.18961833
2	Camp Disaster	Kincaid/ Wills Point	646544	3340362	97.47782734	30.18588434
3	Dry Creek	Wills Point	647033	3339988	97.47280157	30.18245141
4*	Red Bluffs	Wilcox/Carrizo	665802	3328145	97.27977441	30.07320962
5	Cedar Creek	Carrizo	665775	3322808	97.28088615	30.02507091
6	—	Carrizo/Reklaw	666647	3322523	97.27189139	30.02238166
7	Bombshell Bluff	Reklaw	669198	3322868	97.24539331	30.02514375
8	—	Reklaw	669300	3321400	97.24456925	30.01188775
9	Devil's Towhead	Reklaw	670455	3322477	97.23242628	30.02144148
10	Devil's Eye	Reklaw	670430	3323038	97.23259512	30.02650624
11	—	Reklaw	670650	3323193	97.23029796	30.02787652
12	Kennedy Bluff	Queen City	673424	3325887	97.20109489	30.05178395
13	—	Queen City	676634	3322557	97.16837261	30.02128701
14	Gazley Creek	Queen City	677089	3321572	97.16382018	30.01233516
15	Smithville	Weches	677461	3321663	97.15994147	30.01310444
16	—	Sparta/Cook Mountain	678132	3321745	97.15297330	30.01374664
17*	Shipp's Ford	Cook Mountain	684669	3319222	97.08566000	29.99002179

the Sparta Sand and the lower section of the Cook Mountain Formation are exposed on the right bank (Locality 16), at a point corresponding to Deussen's (1924) locality 263.

There are no further marine fossil-bearing outcrops until just below the Bastrop-Fayette County line, where fossiliferous Cook Mountain Formation clay is poorly exposed on the right bank of the river, about 12 km downstream of the Smithville bridge (Locality 17, not shown in figures). This is the Shipp's Ford locality, also called White Bluff and Grassmeyer's Landing, corresponding to Deussen's (1924) locality 265.

CONCLUSIONS

Over the period of more than a century since Penrose documented his trip down the Colorado River, the river has been dammed, its flow regulated, and its shoreline converted from wilderness to trailer parks, residential homes, and golf courses. The locations that were visited and collected in the late 1800s can still be found today (Table 1), but their availability for study is being rapidly diminished by the increasingly more intense private development of the Colorado River valley.

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DIET OF PLEISTOCENE *PARAMYLODON HARLANI*
(XENARTHRA: MYLODONTIDAE): REVIEW OF METHODS AND
PRELIMINARY USE OF CARBON ISOTOPES

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Abstract.—The use of carbon isotopic evidence for determination of dietary preference was previously restricted to the use of enamel (with the exception of some archaeological work), because other materials are more susceptible to diagenesis. For this reason, ground sloths were not included in prior studies. However, the abundance of these animals in deposits of North and South America necessitate a better understanding of their ecology. While sloths lack enamel, their teeth do consist of two layers of dentine: a harder outer layer surrounding a softer inner core. This study sampled both layers of dentine from a lower molariform tooth of *Paramylodon harlani* and from dentine and enamel of animals of known dietary preference. All samples were taken from fossils from the Ingleside fauna, San Patricio County, Texas. The carbon isotopic signatures from the enamel of the grazer *Bison antiquus* and the browser *Palaeolama mirifica* very closely follow expected values, at -0.4‰ and -12.2‰ respectively. Their dentine values lie intermediate to those extremes. Both the outer and inner layers of dentine from the ground sloth, *Paramylodon harlani*, show $\delta^{13}\text{C}$ values of near -4‰, in the range expected of mixed feeders, but closer to the carbon isotopic composition of modern and fossil grazers. Although this study does suggest the validity of geochemical analysis of sloth teeth in dietary determinations, caution must be used. Extent of diagenesis must be evaluated at least in part by also considering samples from animals of known diet, taken from the same locality.

Ground sloths (Mammalia: Xenarthra) belong to a group of extinct, large herbivores originating on and confined to South America through most of the Cenozoic. They reached North America in at least two pulses of immigration, the first in the early Hemphillian (late Miocene), and subsequently in the late Blancan (late Pliocene). The latter event was part of the Great American faunal interchange corresponding with the emergence of the Panamanian land bridge (Hirschfeld & Webb 1968; Marshall et al. 1982; Hirschfeld 1985). When present in a fauna, ground sloths often are abundant. Unfortunately, their unique morphology has

hampered previous attempts to evaluate their ecological position, especially in diet. Traditional methods of dietary analysis use modern analogs, tooth and skull morphology, and dung contents to determine if an herbivore was primarily a grazer, browser, or mixed feeder. A more recently developed technique utilizes the carbon isotopic signature incorporated during the ingestion of plants (e.g., DeNiro & Epstein 1978). This analytical method has helped clarify ecosystem partitioning in some paleontological faunas (e.g., MacFadden 1998; MacFadden et al. 1999). Sloths and other xenathrans are not included in most geochemical studies, even when abundant in the fauna (e.g., MacFadden & Shockey 1997), because they lack the requisite material usually examined isotopic analysis, tooth enamel.

Sloth teeth are composed of two types of dentine, a hard outer layer encapsulating a softer inner layer (Fig. 1). This current study begins to evaluate the possibility of using the isotopic composition of the harder layer as a proxy for enamel in diet determination. In order to assess any diagenetic alteration, samples were also taken from both a known grazer and browser. All samples come from the late Rancholabrean (late Pleistocene) age Ingleside fauna (Lundelius 1972).

The isotopic value of teeth is incorporated during development and therefore only represents the diet during that time. Because juveniles may differ from the adults in diet, it is important to only use teeth from a mature individual. Most mammals have a deciduous set of dentition followed by an adult series, but sloths only have a permanent generation of teeth (Grassé 1955; Naples 1982). The teeth in juvenile sloths are conical, while adult teeth are parallel-sided; therefore adult dentition is easily recognized for sloths. Generally, the most posterior teeth in the skull are the last to erupt; therefore identification of tooth position is helpful to obtain the tooth formed during the oldest age. Most sloths show little differentiation of molariform teeth, but *Paramylodon harlani* teeth, especially the lower third molar, can be precisely identified (Figure 1).

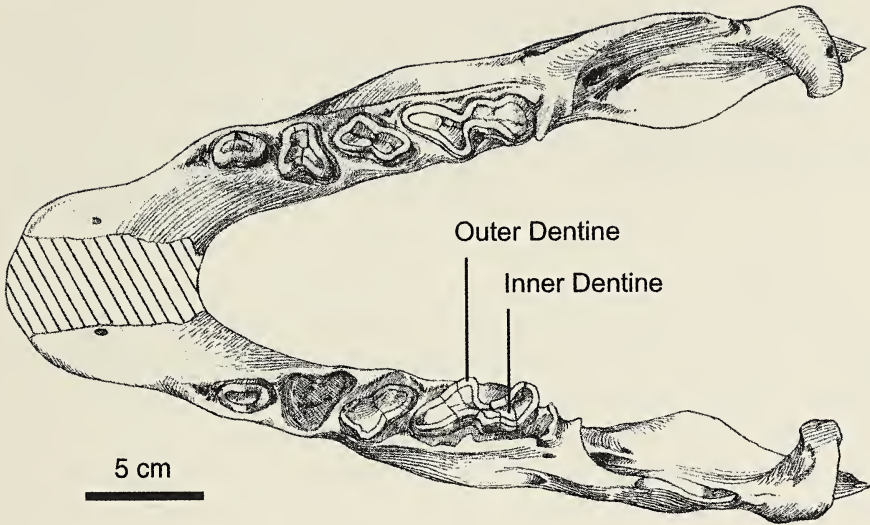


Figure 1. Mandible of *Paramylodon harlani* from Ingleside, with tooth parts labeled. Sloth teeth lack enamel, but have a harder outer layer of dentine surrounding a softer inner layer. Modified from Lundelius (1972).

Paleontologists have debated the diet of *Paramylodon harlani* since the early 1900s, reaching no consensus (Table 1). Considering the problematic standing, any additional evidence is justified.

BACKGROUND AND PREVIOUS STUDIES

Methods of Dietary Analysis

Recreating biology from fossils has often included considerable speculation. Even rigorous studies can sometimes misjudge diet due to phylogenetic constraints in the morphology (MacFadden et al. 1999). In spite of the difficulties, diet aids in interpretation of the habitat and ecological interactions, thus imploring its continued study. The indirect evidence from herbivores is sometimes the only indication of plant types in the area, because the fluctuation of herbivore abundance yields insight to the climatic transitions of an area (Wang et al. 1994; Cerling et al. 1997; 1998).

Table 1. Proposed diet of *Paramylodon harlani*.

Browser	Grazer	Mixed
Lull (1915)	Parker (1885)	Stock (1920)
Dalquest & Schultz (1992)	Brown (1903)	Stock (1925)
	Allen (1913)	Naples (1989)
	Webb (1978)	

Modern analogs.—Comparison to taxonomically similar mammals in modern faunas is the primary method of deducing the paleoecology of an animal. This can only be accomplished with confidence for species for which there are close modern analogs, effectively eliminating many extinct groups from consideration. At some level all life is related, and therefore it is possible to find a living, though not necessarily close, relative. The arbitrary rank of genus was suggested as the level at which such analogs are useful (Shotwell 1955). Unfortunately the genera of modern tree sloths have no known fossil representatives and it is unclear how closely related *Paramylodon* is to extant taxa.

Two genera of tree sloths live today in Central and South America, the two-toed sloth, *Choloepus*, and the three-toed sloth, *Bradypus*. Extant sloths live entirely in trees, and their diet consists almost exclusively of leaves, buds, and fruits, much of which comes from the cecropia tree (e.g., Britton 1941; Lundy 1952). Fossil tree sloths are not known, but paleontological records of ground sloths extend to the Deseadan (early Oligocene) of South America (Hirschfeld 1985; Marshall & Cifelli 1990). Further, the phylogenetic relationship between these groups is unclear (Gaudin 1995), although the hypothesis of Gaudin (2004) has a very distant relationship between mylodont sloths, including *Paramylodon*, and the living *Bradypus* and *Choloepus*. The validity of this comparison is also quickly questioned considering the immense size difference of these animals; the body mass of ground sloths is as much as four orders of magnitude greater than that of tree sloths (Fariña et al. 1998; Adam 1999).

Morphology.—Morphological features independent of taxonomic affiliation can sometimes give clues to the diet. This is advantageous when there is no modern analog, or when the group being studied has changed its ecological behavior. Three features in particular are the most utilized in this way: teeth, muzzle shape, and musculature attachments.

Grasses contain abrasive silica structures called phytoliths that quickly erode teeth during grazing. Consumption of grass may also be responsible for increased amounts of abrasive sediment ingested as compared to a diet of browse. Compensation for this additional wear is achieved by increasing the height and complexity of these teeth (Fortelius 1982; 1985; Janis 1986; 1990). Shorter, simpler teeth are sufficient for a diet of leaves. The most familiar character representing a grazing diet is the presence of high-crowned, or hypsodont teeth. This connection between tooth size and diet is well documented in the study of horse evolution and the overall trend from browsing to grazing (e.g., Kowalevsky 1873; Matthew 1926; Simpson 1953; MacFadden 1992). The teeth of ground sloths are hypselenodont, the extreme case of hypsodonty, and grow throughout life with an open pulp cavity. However, their teeth are very simple in pattern, often consisting of only a simple peg. This combination of characters is difficult to interpret because hypselenodonty typically indicates a grazing diet, but simple occlusal patterns suggest a browsing diet. An additional line of morphological evidence, tooth microwear of herbivores (e.g., Walker & Teaford 1989; Solounias & Moelleken 1992a; 1992b; Solounias & Hayek 1993; Rivals & Deniaux 2003), may prove useful when applied to sloths. This method reveals the most recent diet of the animal before death, which may not be typical of the entire life of the animal (Solounias et al. 1988).

Another adaptation for eating grass is the complex folding of the enamel in the teeth of herbivores. Although relatively complex for a xenarthran tooth, the molariform dentition of *Paramylodon* consists only of simple lobes that show much variation in development,

even within the same population (Stock 1925). Development of cementum in mylodont sloths, which includes *Paramylodon*, was presented as evidence for a grazing habit (Parker 1885), but this character also occurs in the living tree sloths (Ferigolo 1985), which are browsers.

A narrow snout allows an animal to selectively pick the part of the plant to eat, obtaining the most nutritious portions, while a wide muzzle allows more food to be cropped from a flat surface (Solounias & Moelleken 1993; Dompierre & Churcher 1996). While the shape of the muzzle and incisors are useful for dietary interpretations in many extant and fossil animals, it does not apply to ground sloths. They lack incisors, probably using their upper lips or tongue against the large, spatulate mandibular symphysis (pre-dental spout) to crop food (Naples 1989). It is not known if the shape of the premaxilla can be correlated to diet. Grazers process larger volumes of more abrasive food and therefore have larger masticatory muscles than browsers, as inferred by attachment scars on both the skull and jaw (Bramble 1978; Solounias et al. 1995). Analysis of facial musculature suggests that *Paramylodon harlani* was a mixed feeder, though better adapted for grazing than browsing (Naples 1989).

Dung contents.—In the rare localities where fossil vertebrates and plants co-occur, the integration of flora and fauna allows for insights that may be applied to other localities and situations. Identification of plant fragments in dung balls associated with the extinct North American megatheriid sloth *Nothrotheriops shastensis* determined the browsing diet of that taxon in northern Arizona (Hansen 1978). While it may be reasonable to assume most other populations of that species had a similar diet, it may not extend to other sloth taxa. Remains of a species more closely related to *Paramylodon*, *Mylodon darwini*, was found in a South American cave with dung that suggested a grassland environment (Salmi 1955; Moore 1978), but this interpretation was subsequently

challenged (Heusser et al. 1992). Also, an overestimate of grasses in the diet of herbivores limits the applicability of fecal analyses (Holechek & Valdez 1985).

Carbon Isotopes and Diet

The use of carbon isotopic ratios from fossil tooth enamel of mammalian herbivores in order to determine diet has quickly gained popularity and avoids some problems encountered with the traditional methods of dietary determinations discussed above (e.g., MacFadden & Shockey 1997; MacFadden 1998; MacFadden et al. 1999; Feranec 2003). Differentiation between carbon isotopic ratios in grazers and browsers can be used because plants incorporate carbon isotopes differently. Initial $\delta^{13}\text{C}$ (see Materials and Methods for definition of $\delta^{13}\text{C}$) measurements of plants returned values of averaging -28‰ (Craig 1953; 1954), while subsequent research discovered that some plants gave more enriched values of -14‰ (Bender 1968; 1971). The difference came from sampling plants that follow different photosynthetic methods (O'Leary 1981; 1988). More recent measurements have refined these values and the currently accepted average values are -27‰ and -13‰ respectively (Farquhar et al. 1989; Boutton 1991). The more depleted measurements were taken from plants that use the C_3 (Calvin) pathway, including trees, shrubs, and high elevation/latitude grasses. The relatively enriched values were from corn and other temperate and tropical grasses, which utilize the C_4 (Hatch-Slack) pathway. A third photosynthetic pathway, crassulacean acid metabolism (CAM), is found in desert plants and other succulents which are assumed to not comprise a significant component of the flora at Ingleside in the late Pleistocene. The apatite in the enamel of teeth from modern mammalian herbivores shows an additional fractionation in the form of an enrichment of about +14‰ from that of the plant materials consumed (Cerling & Harris, 1999). Therefore the $\delta^{13}\text{C}$ of grazers should average about 1‰, and that of browsers should near -13‰.

MATERIALS AND METHODS

All fossils come from the Ingleside fauna (Texas Memorial Museum locality 30967), San Patricio County, Texas, which was referred to the Rancholabrean (late Pleistocene) North American Land Mammal Age (Lundelius 1972). Precise age determination is problematic as there is a lack of radiometric, and little superpositional, data, but Lundelius (1972) suggested a time range of 122,000 to 19,000 years.

Analytical methods generally follow those outlined by Koch et al. (1997) for collecting and preparing biological apatite from tooth enamel. The teeth were cleaned to remove any loose surficial contaminants, and then samples were drilled. The edges were removed to obtain a pristine sample, as far from any potential surficial alteration as possible. Care was also taken to ensure the separation of enamel and dentine. After pulverizing, 50 mg of each sample was soaked in 2 mL of 3% NaOCl. The mixture was continuously agitated with the lids loose (so CO₂ from oxidation could escape) for one and three days for the enamel and dentine respectively. The samples were centrifuged and the fluid removed by aspiration through a pipette. Distilled water was added to each sample, which was again mixed and centrifuged with the resultant fluid being removed. This was repeated five times. The samples were then soaked in a 2 mL solution of 1N acetic acid-calcium acetate buffer for two days to remove any carbonate minerals. The rinsing procedure described above was repeated to clean the samples, which were then allowed to air dry.

On-line purification and extraction followed standard techniques detailed by MacFadden & Cerling (1996) and MacFadden et al. (1996). The samples were analyzed for their carbon isotopic composition using a VG Prism mass spectrometer in the Department of Geological Sciences at The University of Texas at Austin. All results are given in the standard delta notation (δ) as the deviation in parts per mil (‰) of the sample from that of the V-PDB standard for carbon (Coplen 1994), where:

$$\delta^{13}\text{C} = [({}^{13}\text{C}_{\text{sample}}/{}^{12}\text{C}_{\text{sample}}/{}^{13}\text{C}_{\text{standard}}/{}^{12}\text{C}_{\text{standard}}) - 1] \times 1000.$$

Samples were taken from a presumed grazer, *Bison antiquus*, a presumed browser, *Palaeolama mirifica*, and the ground sloth, *Paramylodon harlani*, all from the Ingleside fauna. Enamel and dentine from *Bison* and *Palaeolama* and both layers of dentine from the sloth were sampled. Previous examination of enamel from fossil *Bison* from Florida produced average $\delta^{13}\text{C}$ values of -3.4‰ for middle Rancholabrean faunas and -1.1‰ for late Rancholabrean faunas (Feranec & MacFadden 2000). Those values are consistent with the diet of a grazer. The average $\delta^{13}\text{C}$ value for enamel from *Palaeolama* from Tarija, Bolivia, was -11.4‰ (MacFadden & Shockey 1997), consistent with the diet of a browser. Enamel samples from the *Bison* and *Palaeolama* from Ingleside were analyzed to verify that isotopic signatures of both grazers and browsers were recorded in the fossil locality and to confirm that values from the enamel were consistent with that from other localities examined in previous studies. Dentine from *Bison* and *Palaeolama* was also sampled; if the dentine from *Paramylodon* at Ingleside was diagenetically altered, the dentine from *Bison* and *Palaeolama* should be similarly changed.

ANALYTICAL RESULTS AND DISCUSSION

The enamel values of *Bison* and *Palaeolama* (Fig. 2) represent the extreme ends of the grazing-browsing spectrum. The *Bison* $\delta^{13}\text{C}$ value of -0.4‰ and the *Palaeolama* value of -12.2‰ (Fig. 2) fall within the expected range of grazers and browsers respectively, as well as within previously observed ranges of fossil *Bison* (MacFadden & Feranec 2000) and *Palaeolama* (MacFadden & Shockey 1997). In each of these animals the dentine values differ by slightly more than 4‰ from that of the enamel, but in opposite directions. The Ingleside *Bison* and *Palaeolama* had $\delta^{13}\text{C}$ values of -4.6‰ and -8.1‰ respectively. Both layers of dentine in *Paramylodon* produced values of about -4‰ (-3.5‰ and -4.1‰).

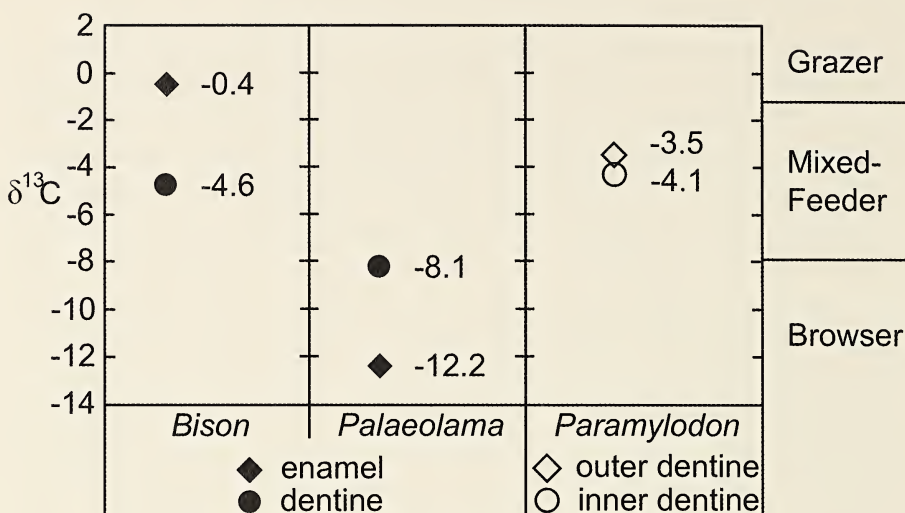


Figure 2. Carbon isotopic results from Ingleside, Texas. The vertical axis shows the $\delta^{13}\text{C}$ of the sample. The enamel value for *Paramylodon* is that of the outer layer of dentine. Texas Memorial Museum (TMM) specimens sampled were *Bison*, left up-per first or second molar, TMM 30967-1097; *Palaeolama*, right upper first or second molar, TMM 30967-2573; and *Paramylodon*, right lower fourth molariform, TMM 30967-2430. The divisions shown between grazers and mixed-feeders (-1.3‰) and between mixed-feeders and browsers (-7.9‰) are from Feranec (2003).

Before an interpretation of the *Paramylodon* results can be interpreted, the dentine values of the other taxa must be examined first. There are two possible scenarios for the discrepancy between the dentine and enamel $\delta^{13}\text{C}$ values for the Ingleside *Bison* and *Palaeolama*: the dentine is diagenetically altered or the dentine values are a biological product.

In the first scenario, the carbon isotopic compositions of both dentine and enamel initially were the same (or similarly offset), but were subsequently altered. Because the *Bison* dentine sample was depleted relative to the enamel by about 4‰ and the *Palaeolama* sample was enriched by the same amount, the altering fluid must then have had an intermediate $\delta^{13}\text{C}$ value of about -6‰. The *Paramylodon* $\delta^{13}\text{C}$ values are similar to the dentine of *Bison* and if

subject to similar diagenesis would alter in the same manner, meaning the original value must have been near 0‰, close to the value of the *Bison* enamel. The author is unaware of a potential altering fluid near Ingleside with a $\delta^{13}\text{C}$ of -6‰. Because the Ingleside fauna is on the coast, both marine and surface waters could be in contact with the fossils, but the $\delta^{13}\text{C}$ values of these waters are 0‰ and 2-4‰ respectively (Anderson & Arthur 1983).

Alternately, the dentine values may represent a biological effect and were not altered. Dentine values may be offset from enamel during tooth formation due to different constraints during tooth formation. Grazers build a more hypsodont, more complex tooth that usually contains cementum surrounding the enamel. This different construction may be reflected in the isotopic signature of the dentine. In the case of *Bison* and *Palaeolama*, the dentine $\delta^{13}\text{C}$ values may change during the life of the individual, because it is a vascular tissue. In *Paramylodon*, however, the outer layer of dentine lack vascular canals (Ferigolo, 1985). The difference in hardness of the inner and outer dentine layers is extreme and causes the complex wear facets seen in many xenarthrans (Naples 1982, 1995). If the teeth had undergone diagenesis it would be expressed differently in the two distinct types of dentine in *Paramylodon*. Since the carbon isotopic ratios of both types of dentine in *Paramylodon* are very similar, there were probably not any significant diagenetic effects. In this scenario *Paramylodon* was a mixed feeder.

The first scenario requires an altering fluid more depleted in $\delta^{13}\text{C}$ than expected for either marine or surface water, but allows for diagenesis of the *Paramylodon* dentine. The second scenario implies a different biological effect on dentine of different animals. Neither situation can be excluded as a possibility, although the presence of an altering fluid at Ingleside having such a depleted $\delta^{13}\text{C}$ value is here regarded as less likely. There is very little difference in $\delta^{13}\text{C}$ of the inner and outer layers of dentine in *Paramylodon*.

CONCLUSION

This study is the first to utilize carbon isotopes in an investigation of the diet of a sloth. The similarity between the different dentine layers suggests the isotopic signature of *Paramylodon* is unaltered at this locality; diagenesis would likely have impacted the inner and outer layers differently. These carbon isotopic data indicate that *Paramylodon harlani* from Ingleside, Texas, probably had a mixed diet dominated by grass. The other possible scenario, here considered less likely, is that the *Paramylodon* dentine was altered by the same fluid that altered the *Bison* and *Palaeolama* dentine. In this scenario, *Paramylodon* originally had an isotopic signature suggesting the diet of a grazer. There is no evidence in either scenario for *Paramylodon* being a browser.

As this study contained only two samples from each of three teeth, much room is left for further refinement. Diagenesis in the sloth dentine may be addressed through analysis of more teeth and from multiple samples along a vertical gradient on a single tooth. Altered specimens will widely vary in $\delta^{13}\text{C}$, while pristine samples show much less fluctuation (Koch et al. 1997). Additionally, Ingleside and many other fossil localities contain multiple species of sloths. If they partition the ecosystem in a manner seen in other large herbivores, they will show different isotopic signals, reflective of different diets. While extant sloths are dramatically different from their extinct relatives, future inclusion of samples from modern teeth will help elucidate the variation between the two dentine types.

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CHARACTERISTICS OF CHIGGER MITE (*HANNEMANIA* SP.)
PARASITISM ON *ELEUTHERODACTYLUS MARNOCKII*
(AMPHIBIA: LEPTODACTYLIDAE)

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Abstract.—*Hannemania* mite larvae are known to infest a variety of amphibian species but no data exist for characteristics of *Hannemania* parasitizing the cliff chirping frog, *Eleutherodactylus marnockii*. Ninety-four museum specimens of *E. marnockii* from central Texas were examined to address potential differential parasitism by sex and the distribution of *Hannemania* mites found encapsulated within this host. Additionally, mites from one specimen of *E. marnockii* were found to be *Hannemania monticola*. No difference was found in the number of mites encapsulated in females or males despite considerable sexual dimorphism in body size and a strong effect of body size on the number of mites. Male and female *E. marnockii* have similar home ranges and these results support a home range hypothesis to explain the similarity in the number of mites found in males and females. The hind legs and hind feet of *E. marnockii* had about 40% more mites than all other regions of the body combined. This may be because hind legs and hind feet have a greater frequency of contact with mites, or the mites prefer to attach in the legs and feet.

Larval *Hannemania* mites (Acari: Leeuwenhoekiidae) burrow through the skin of salamanders and anurans and encapsulate within the stratum spongiosum of the dermis (Hyland 1950; 1961; Duszynski & Jones 1973; Grover et al. 1975). The characteristics of the capsule for both salamanders and anurans are histologically identical. Mites are encapsulated in a layer of connective tissue that compresses and distorts the stratum compactum and causes acanthosis of epidermal cells adjacent to the capsule (Grover et al. 1975). Externally, larvae of *Hannemania* appear as conspicuous orange to red colored pustules of approximately 1 mm diameter beneath the skin of amphibian hosts. Mites can remain inside hosts for more than six months in the laboratory (Hyland 1950; 1961). It is unclear what cues cause mites to emerge. When hosts die the

larvae quickly emerge and burrow into the soil to undergo the nonparasitic phase of the life cycle as soil mites (Hyland 1961).

There are varying degrees of host taxa specificity for *Hannemania* mite larvae. More than 12 species of salamanders are parasitized by *H. dunni* (Rankin 1937; Loomis 1956; Duncan & Highton 1979; Winter et al. 1986; McAllister et al. 1995a; 1995b; Regester 2001). At some localities, certain salamander taxa are not parasitized by *Hannemania* mites (e.g. *Plethodon albagula*, *P. serratus*) despite being syntopic with salamanders that are heavily parasitized (Duncan & Highton 1979; Winter et al. 1986; Anthony et al. 1994; Regester 2001; McAllister et al. 2002). *Hannemania hylae* parasitizes *Hyla cadaverina*, *H. arenicolor*, *Rana berlandieri*, *R. palustris*, and *Eleutherodactylus guttillatus* (Welbourn & Loomis 1975; McAllister et al. 1995c; Sladky et al. 2000; Jung et al. 2001). *Hannemania bufonis* differs from other *Hannemania* in that throughout most of its range it is restricted to a single host taxon, *Bufo punctatus*, although in Mexico it also parasitizes *Bufo mazatlanensis* (Loomis & Welbourn 1969; Welbourn & Loomis 1975; Goldberg et al. 2002).

Several ecological costs have been established for individuals that are heavily parasitized by *Hannemania* mites. Heavily parasitized male *Plethodon angusticlavius* are less aggressive in territorial disputes during fights with males that have low parasite loads (Maksimowich & Mathis 2000). Males with high parasite loads also have longer latency to foraging times compared to males with low parasite loads (Maksimowich & Mathis 2000). Infestation of the snout can cause damage to the nasolabial groove (Anthony et al. 1994) and this can reduce the chemosensory capability of salamanders and in turn reduce foraging ability and mate acquisition (Jaeger 1981; Dawley 1984). Nonparasitized females can detect parasite loads of males through use of pheromonal markers and nonparasitized females appear to prefer males that also have low parasite loads (Maksimowich & Mathis 2001).

The encroachment of the dermis, patterns of host specificity, and costs associated with being parasitized by *Hannemania* mites suggests that amphibians and mites may coevolve in interesting ways. While some work has focused on *Hannemania* parasitizing salamanders, little data are available for anurans. *Eleutherodactylus marnockii* is a leptodactylid frog endemic to the Edwards Plateau of central Texas. These frogs are frequently parasitized by *Hannemania* mites but no data exist on how these frogs interact with their parasitic mites (Lynch 1970; Dixon 2000) or what species of *Hannemania* parasitize *E. marnockii*. Ninety-four museum specimens of *E. marnockii* were examined to (1) identify those species of *Hannemania* which parasitize *E. marnockii* (2) determine the degree of infestation based upon the gender of the host and (3) determine any differences in mite accumulation rates for different body regions of *E. marnockii*.

MATERIALS AND METHODS

Specimens of *Eleutherodactylus marnockii* were examined at the Texas Cooperative Wildlife Collections (TCWC) and University of Texas-Arlington Collection of Vertebrates (UTA). Collection localities for each specimen examined are provided in Table 1.

Four mites from one specimen of *E. marnockii* were cleared in lactophenol and mounted on semipermanent slides with Hoyer's medium before identification under a Nikon Optiphot 2 phase contrast and differential interference microscope. Mites were deposited in the Colección Nacional de Ácaros (CNAC) of the Instituto de Biología at Universidad Nacional Autónoma de México in México, D. F.

Frogs were dissected and gonads observed to determine the sex of each individual. Fifty-eight individuals (33 female and 25 male) were examined to test whether total mite numbers differ between males and females. It is unknown if body size is a dimorphic character in *E. marnockii* and snout-vent length (SVL) was measured to test this hypothesis.

Table 1. Accession numbers and collection information for the 94 specimens of *Eleutherodactylus marnockii* examined during this study. TCWC=Texas Cooperative Wildlife Collections; UTA-A=University of Texas-Arlington Collection of Amphibians; SND=Sex not determined.

Mus. No	Date	County	Locality	Sex	SVL (mm)	Total Mites
TCWC 79862	10-Jun-98	Bandera	5 mi N Vanderpool, Lost Maples St Natl Area	F	31.9	13
TCWC 79863	6-Aug-98	Bandera	5 mi N Vanderpool, Lost Maples St Natl Area	F	24	12
TCWC 9234	10-Apr-52	Bexar	2 mi N Helotes	F	34.6	32
TCWC 9235	10-Apr-52	Bexar	2 mi N Helotes	F	33.3	55
TCWC 4782	29-Oct-50	Blanco	8 mi NE Blanco	F	34.8	35
TCWC 64283	18-Mar-86	Blanco	Pedernales Fall State Park	F	31.6	152
TCWC 52190	-	Edwards	27.4 mi NW Rocksprings	F	27.7	0
TCWC 74501	11-Nov-64	Edwards	28 mi ENE Rock Springs	F	34.5	46
TCWC 52191	-	Edwards	27.4 mi NW Rocksprings	F	39.7	73
UTA-A 56729	27-Mar-04	Edwards	Campwood	F	32.9	25
UTA-A 56730	27-Mar-04	Edwards	Campwood	F	24.5	9
TCWC 5071	23-Mar-51	Hays	6 mi SW San Marcos, Williams Cave	F	34.1	29
TCWC 7140	28-Jan-50	Hays	6 mi SW San Marcos	F	30.9	11
TCWC 5070	23-Mar-51	Hays	6 mi SW San Marcos, Williams Cave	F	32.4	4
TCWC 30741	5-Apr-70	Hays	Fern Bank Springs on Blanco River	F	25.5	5
TCWC 30740	5-Apr-70	Hays	Fern Bank Springs on Blanco River	F	22.1	27
TCWC 9233	16-Mar-52	Hays	6 mi SW San Marcos	F	37.2	25
TCWC 30738	5-Apr-70	Hays	Fern Bank Springs on Blanco River	F	30.8	30
UTA-A 1549	4-Apr-69	Hays	Fern Bank on Blanco River near Wimberly	F	22.2	8
UTA-A 309	16-Aug-65	Hays	Fern Bank on Blanco River near Wimberly	F	21.8	0
UTA-A 1119	13-Jun-64	Hays	6.3 mi NE of Wimberly	F	32.8	3
UTA-A 1118	22-Aug-64	Hays	Fern Bank, 6.3 mi N Wimberly	F	18.1	15
TCWC 38862	16-Apr-72	Kendall	Able's Grotto, 0.4 mi W Centruy Caverns	F	29	66
TCWC 63806	13-Jun-85	Kinney	4.7 mi N Jct FM 334 & 3199 on 3199	F	36.3	56
UTA-A 52712	9-Jul-71	Real	20.3 km W jct 83 on farm road 337	F	33.2	65
UTA-A 56731	9-Apr-04	Terrell	Independence Creek; hunting area #3	F	31.7	61
UTA-A 40076	3-Sep-91	Travis	Austin, 1124 S 3rd street	F	20.7	7
TCWC 36822	30-Jun-64	Uvalde	17 mi NW Sabinal; in crevices	F	20.9	4
TCWC 49065	1-Nov-75	Uvalde	13.0 mi N Uvalde, David Guiley Ranch, Hwy 83	F	28.5	3
TCWC 64764	26-May-86	Val Verde	18 mi SE Pandale on Hwy 1024	F	31	8
TCWC 74511	30-Mar-72	Val Verde	12 mi N Comstock	F	32.5	14
UTA-A 7131	6-Aug-72	Val Verde	6.0 mi N Langtry	F	33.3	87
UTA-A 45794	20-May-94	Val Verde	On US 277, ca. 5.0 mi S Loma Alta	F	35.5	29
TCWC 79861	10-Jun-98	Bandera	5 mi N Vanderpool, Lost Maples St Natl Area	M	23.4	18
TCWC 13506	4-May-57	Bandera	13 mi W Medina, Hwy 1336	M	25.1	41
TCWC 53977	22-Jul-76	Bexar	San Antonio, 239 Bambridge Ave	M	25	0
TCWC 13504	21-Apr-57	Comal	Landa Park, New Braunfels	M	26.8	55
TCWC 74505	27-Jan-67	Edwards	26 mi NE Rock Springs	M	19.9	11
TCWC 9236	12-Apr-52	Hays	6 mi SW San Marcos	M	26.6	15
TCWC 33301	1-Apr-70	Hays	Wimberly, Fern Bank Springs	M	23	47
TCWC 33303	1-Apr-70	Hays	Wimberly, Fern Bank Springs	M	20.8	10
TCWC 27068	30-Mar-68	Hays	4 mi E Wimberly	M	26.8	41
UTA-A 19499	26-Apr-86	Hays	San Marcos, Dudley Johnson Park, S side San Marcos River	M	22.8	2
UTA-A 19498	26-Apr-86	Hays	San Marcos, Dudley Johnson Park, S side San Marcos River	M	19.8	0
UTA-A 310	16-Aug-65	Hays	Fern Bank on Blanco River near Wimberly	M	23.8	0
UTA-A 311	16-Aug-65	Hays	Fern Bank on Blanco River near Wimberly	M	24.2	6
UTA-A 254	16-Aug-65	Hays	Fern bank at Blanco River	M	24.3	3
UTA-A 256	16-Aug-65	Hays	Fern Bank at Blanco River	M	20.2	0
TCWC 63810	13-Jun-85	Kinney	4 mi N Jct FM 334a, 3199 on 3199	M	19.6	0
UTA-A 17418	6-Oct-84	Pecos	St. Hwy 285, 47.9km N Jct St. Hwy 285 and US Hwy 90	M	19.3	1
TCWC 74500	2-Jul-70	Terrell	21 mi N Dryden	M	32.9	80
UTA-A 40075	11-Nov-92	Travis	Austin	M	22.2	8

Table 1. Cont.

Mus. No	Date	County	Locality	Sex	SVL (mm)	Total Mites
TCWC 49064	22-May-75	Uvalde	13.0 mi N Uvalde, David Guiley Ranch, Hwy 83	M	24.6	1
UTA-A 56728	27-Mar-04	Val Verde	Near con. of Dry Devil's River, Goldmine Canyon Ranch	M	31.5	40
UTA-A 32839	16-Jun-87	Val Verde	6.0 km N Del Rio at Lake Amistad access near US Hwy 277/377	M	26	36
UTA-A 20843	24-May-86	Val Verde	6.0 km N Del Rio near US Hwy 377, lake access	M	21.9	0
UTA-A 21070	17-Mar-87	Val Verde	24.9 km SE Comstock on US Hwy 90	M	18.3	2
UTA-A 21085	19-Mar-87	Val Verde	9.5 km W jet US Hwy 377 and Rough Canyon Recreational Road 2	M	22	6
TCWC 13509	4-May-57	Bandera	10 mi SW Medina	SND	18.6	1
TCWC 13507	4-May-57	Bandera	13 mi W Medina, Hwy 1336	SND	20.5	2
TCWC 13499	21-May-55	Bexar	San Antonio	SND	24.3	0
TCWC 53978	22-Jul-76	Bexar	San Antonio, 239 Bambridge Ave	SND	22.9	0
TCWC 65532	18-Apr-87	Bexar	5.5 mi S Boerne, Mueller Ranch	SND	14.4	2
TCWC 13498	21-May-55	Bexar	San Antonio	SND	20.2	0
TCWC 34458	2-Sep-57	Burnet	5.5 mi W Marble Falls	SND	32.6	6
TCWC 34455	2-Sep-57	Burnet	5.5 mi W Marble Falls	SND	18.9	1
TCWC 34457	2-Sep-57	Burnet	5.5 mi W Marble Falls	SND	21.5	0
TCWC 13500	21-Apr-57	Comal	Landa Park, New Braunfels	SND	26.7	3
TCWC 13503	21-Apr-57	Comal	Landa Park, New Braunfels	SND	22.4	20
TCWC 13502	21-Apr-57	Comal	Landa Park, New Braunfels	SND	26.9	97
TCWC 52187	-	Edwards	27.4 mi NW Rocksprings	SND	22.7	7
TCWC 52185	-	Edwards	27.4 mi NW Rocksprings	SND	33.5	0
TCWC 52189	-	Edwards	27.4 mi NW Rocksprings	SND	23.7	78
TCWC 74508	27-Jan-67	Edwards	26 mi NE Rock Springs	SND	25.2	33
TCWC 74504	27-Jan-67	Edwards	26 mi NE Rock Springs	SND	17.5	0
TCWC 74502	27-Jan-67	Edwards	26 mi NE Rock Springs	SND	18.5	24
TCWC 74507	27-Jan-67	Edwards	26 mi NE Rock Springs	SND	17.9	49
TCWC 52188	-	Edwards	27.4 mi NW Rocksprings	SND	15.4	0
TCWC 9232	15-Feb-52	Hays	6 mi SW San Marcos	SND	34.1	27
TCWC 27070	30-Mar-68	Hays	4 mi E Wimberly	SND	25.6	66
TCWC 27071	30-Mar-68	Hays	4 mi E Wimberly	SND	14.6	0
TCWC 30739	5-Apr-70	Hays	Fern Bank Springs on Blanco River	SND	24.6	1
TCWC 54983	11-Jun-72	Kendall	12 mi N Del Rio	SND	32.4	12
TCWC 40371	16-Apr-72	Kendall	0.4 mi W Century Cavern, Able's Grotto	SND	20.9	0
TCWC 38861	16-Apr-72	Kendall	Able's Grotto, 0.4 mi W Centruy Caverns	SND	27.9	62
TCWC 74509	20-Apr-68	Kerr	7 mi E Kerrville	SND	32.9	12
TCWC 6555	6-Mar-49	Kerr	40 mi W Kerrville	SND	21.2	12
TCWC 63809	13-Jun-85	Kinney	4 mi N Jct FM 334a, 3199 on 3199	SND	18.1	3
TCWC 63807	13-Jun-85	Kinney	4 mi N Jct FM 334a, 3199 on 3199	SND	28.5	79
TCWC 38698	19-Apr-68	Medina	0.25 mi W Mico	SND	16.5	0
TCWC 36820	30-Jun-64	Uvalde	17 mi NW Sabinal; in crevices	SND	25.6	8
TCWC 36819	30-Jun-64	Uvalde	17 mi NW Sabinal; in crevices	SND	34.2	27
TCWC 49063	6-Apr-75	Uvalde	13.0 mi N Uvalde, David Guiley Ranch, Hwy 83	SND	24.5	21
TCWC 74510	30-Mar-72	Val Verde	12 mi N Comstock	SND	31.7	16

Eleutherodactylus specimens were placed under a dissecting microscope and the total number of mites encapsulated in the dermis were counted. The number of mites found on the fore limbs, front feet, hind legs and the dorsal head, ventral head, dorsal trunk and ventral regions of the body were counted to address

whether differences exist in the area of attachment for mites. Statistical analyses were performed using SAS version 8.2 and Systat version 8.0. A Kolmogorov-Smirnov test was used to check the data for normality using PROC UNIVARITE and homogeneity of variance was checked with Levene's Test using the HOVTEST function in SAS.

Female body size data were not normally distributed ($D=0.194266$; $P<0.0100$) but male body size data were normally distributed ($D=0.108558$; $P>0.1500$) and the variances were unequal ($F_{1, 56}=4.84$; $P=0.0319$). PROC GLM was used with sex (male, female) as a fixed effect and snout to vent length (SVL) as the dependent variable to test the hypothesis that body size differs between males and females. Because these data violate both the normality and equal variance assumption of *ANOVA*, a Monte Carlo simulation was performed in SAS by randomizing the SVL data and permuting these data in the analysis 1000 times. The sum of squares from the original model was used as the test statistic ($SS=577$) by which to assess the original hypothesis.

To test the hypothesis that the total number of mites was different between the sexes an analysis of covariance (*ANCOVA*) was used to control for the influence of body size. The total number of mites on females was not normally distributed ($D=0.179474$; $P<0.01$) nor were the total number of mites on males ($D=0.245875$; $P<0.01$). Variances were equal ($F_{1, 56}=1.11$; $P=0.2971$). Again, because the data violate assumptions of *ANCOVA*, a Monte Carlo simulation in SAS was performed by randomizing mite totals and permuting these data in the *ANCOVA* analysis 1000 times. The sum of squares for sex ($SS=710$), SVL ($SS=11994$), and the interaction ($SS=943$) from the original *ANCOVA* were used as test statistics by which to assess the original hypothesis. The initial Monte Carlo analysis revealed that the interaction term was non-significant ($P=0.323$). The Monte Carlo analysis was repeated with the interaction term removed from the model and the sums of squares from this analysis were used as test statistics to evaluate

whether there were differences in the number of mites found on males and females while controlling for body size.

To determine whether mites were more frequent on particular areas of the body of *E. marnockii*, an additional 36 museum specimens of undetermined sex were examined and an *ANOVA* using PROC GLM was performed with area of body as a fixed class variable. The distribution of mites found in each area of the body were not normally distributed (fore limbs: $D=0.296258$; $P<0.01$; hind feet: $D=0.233706$; $P<0.01$; fore feet: $D=0.325076$; $P<0.01$; head-dorsal: $D=0.481686$; $P<0.01$; head-ventral: $D=0.459602$; $P<0.01$; hind limbs: $D=0.276562$; $P<0.01$; trunk-dorsal: $D=0.406678$; $P<0.01$; trunk-ventral: $D=0.30448$; $P<0.01$) and the variances were unequal ($F_{7,744}=3.59$; $P<0.0008$). A Monte Carlo simulation in SAS was performed by randomizing the mite data found in each area of the body and permuting these data 1000 times. The sum of squares from the original *ANOVA* was used as the test statistic ($SS=5283$) by which to assess whether the distribution of mites on the body of *E. marnockii* was different. Multiple comparison procedures (Tukey, Ryan's, and Student-Newman-Keuls) were used to evaluate what areas of the body had similar concentrations of *Hannemania* mites.

RESULTS

A single specimen of *Hannemania monticola* was found on one specimen of *E. marnockii* (UTA-A 56732). This species was previously recorded on *Hyla eximia*, *Eleutherodactylus saxatilis* and *Ambystoma rosaceum* from Durango, Mexico (Welbourn & Loomis 1970) and *Rana tarahumarae* from Sonora, Mexico (Goldberg et al. 2002). This is the first record of *Hannemania monticola* in the United States. *Hannemania eltoni*, *H. bufonis*, *H. dunni*, *H. hylae* and *H. multifemoralis* had been recorded on some hosts in Texas but the mites mounted (CNAC 004204-07) are clearly different from the *Hannemania* previously recorded. However specimens of only one sample were mounted and therefore it is not possible at this time to determine if *E. marnockii* is parasitized only by *H. monticola*.

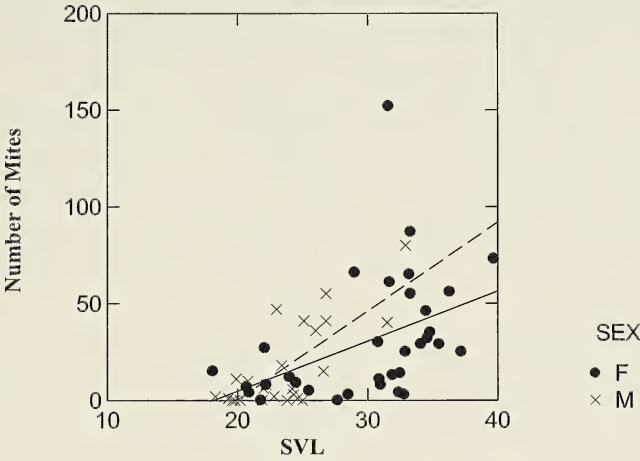
because it is possible to find two different *Hannemania* species on the same host species (e.g., Welbourn & Loomis 1970).

On average, female *Eleutherodactylus marnockii* were about 20% larger than males (Mean Female SVL=29.8 $\pm$ 5.50 mm; Mean Male SVL=23.8 $\pm$ 3.55 mm; $P<0.0001$). Prevalence of *Hannemania* on all frogs examined was 81% and the average abundance of mites on frogs ($\pm$ 1 *SD*) was 22.4 $\pm$ 28.1 with a range of 0–152 (Table 1). The number of mites on females and males was not different ($P=0.55$) and body size strongly influenced the total number of mites found on individual frogs ($P<0.0001$; Fig. 1a, b). The distribution of mites encapsulated on different areas of the body was not uniform ($P<0.0001$); rather, the hind legs and hind feet combined, on average, contained 40% more mites compared to all other regions of the body combined (Table 2).

DISCUSSION

No evidence for differential parasitism by sex was found in this study. Anthony et al. (1994) found that males were infested with more *Hannemania dunni* than females and juveniles in both *Plethodon ouachitae* and *Plethodon caddoensis* and suggested that this may be due to larger home ranges and/or to reduced immunity due to the immuno-suppressive effects of testosterone. Spieler & Linsenmair (1999) did not find differential parasitism in *Endotrombicula*, a similar amphibian mite to *Hannemania* (but found in the Trombiculidae, rather than Leeuwenhoekiidae) infesting *Phrynobatrachus francisci* (Ewing 1931; Kethley 1982). However, they note that low sample sizes ($n=16$) may have caused a type II error because there was a trend towards higher numbers of mites in males compared to females. In this study, there was a tremendous amount of variation in the numbers of mites found on males and females (male mean $\pm$ *SD*=16.9 $\pm$ 22.0 and female mean $\pm$ *SD*=30.6 $\pm$ 32.5). This may result from uncontrolled variation resulting from sampling across time and space as many different localities across more than 50 years were represented in the sample (Table 1). However, the locality “Hays County” consisted of nine

a



b

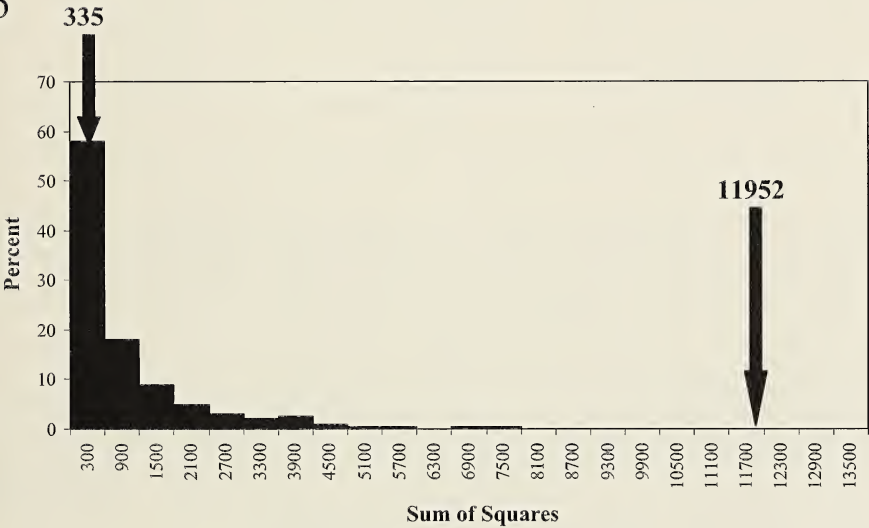


Figure 1. (a) Scatterplot of the number of mites found on males ($n = 25$) and females ($n = 33$) in relation to snout to vent length (SVL). Mean number of mites female = 30.6 ± 32.5 and mean no. of mites male = 16.9 ± 22.0 . (b) Distribution of 1000 permutations from a Monte Carlo ANCOVA to test for differences in the number of mites between males and females while controlling for body size. Sums of squares for sex = 335 and 11952 for SVL. There was no difference in the number of mites in males and females ($P = 0.55$) and there was a strong effect of body size on the number of mites ($P < 0.0001$).

Table 2. Number of mites found on different areas of the body of *Eleutherodactylus marnockii* (n=94). Multiple comparison procedures (Tukey, Ryan's and Student Newman-Keuls) showed that legs and feet had more mites than all other areas of the body.

Area of body	Mean $\pm$ SD (Range)	MCP Result
Fore limbs	2.05 $\pm$ 3.84 (0-19)	B
Front feet	1.73 $\pm$ 3.56 (0-21)	B
Hind legs	6.29 $\pm$ 10.6 (0-85)	A
Hind feet	7.94 $\pm$ 10.9 (0-47)	A
Trunk-Dorsal	1.06 $\pm$ 3.85 (0-31)	B
Trunk-Ventral	2.76 $\pm$ 5.41 (0-35)	B
Head-Dorsal	0.191 $\pm$ 0.627 (0-5)	B
Head-Ventral	0.319 $\pm$ 0.765 (0-4)	B

male and 11 female specimens spanning about 20 years. Performing a separate *ANCOVA* on this small sample did not change the results; there was no differential parasitism by sex when controlling for body size. Future work should focus on securing an adequate sample of males and females from the same locality at the same time to control for these potential effects and to confirm that there is no differential parasitism by sex for *E. marnockii*. However, equivalent numbers of *Hannemania* sp. on both males and females is an interesting result that warrants explanation.

Home range has been suggested as one factor that will influence the number of parasites found on hosts because the sex with the larger home range has a greater probability of being exposed to parasites (Anthony et al. 1994). The home range size of male and female *E. marnockii* is approximately equal (Jameson 1955) and thus the results of this current study are consistent with the home

range hypothesis. Equivalent home ranges for both males and females allows both sexes to be equally exposed to *Hannemania* sp. and thus both sexes obtain the same number of parasites. Another hypothesis that relates to differential parasitism by sex is the immunocompetence handicap hypothesis (Folstad & Karter 1992). High levels of testosterone are correlated with the development of elaborate ornamentation, complex mate attraction signals, and other viability indicators in males but at the same time testosterone causes immunosuppressive effects.

Assuming an obligatory immunosuppression resulting from the maintenance of secondary sexual characters, parasite burdens may be larger in males. Males of *E. marnockii* submit several different advertisement vocalizations (Fouquette 1960). The factors that trigger expression of these different call types are unknown but at some level testosterone is arguably involved. Results of this current study are inconsistent with the immunocompetence hypothesis despite males that maintain complex mate attraction signals. One potentially fruitful avenue would be to explore the frequency of particular call types in relation to parasite loads to determine if such signals may allow females to assay parasite loads in males. Why parasites loads are as high in males and females of *E. marnockii* despite the immunosuppressive effects of testosterone are unclear.

Mites clearly accumulate more on the hind legs and hind feet compared to other regions of the body. This is interesting because there is more surface area for mites to encapsulate on the ventral and dorsal areas of the body compared to all other regions combined. Accumulation of mites on the feet and legs could simply be the result of greater contact with parasites during locomotion or inactive periods; however, mites do not immediately attach once contact is made with the host. Rather, in many cases mites move from place to place on the host and probe the skin before beginning the process of encapsulation (Hyland 1961). The reason for mites choosing the legs and feet over other of the body is unclear but these regions of the body contain more connective

tissue and perhaps this greater connective tissue density allows the mites to more securely encapsulate in the host. Alternatively, perhaps the hind legs and hind feet provide a better environment for larval *Hannemania*.

In *Eleutherodactylus marnockii* it is unknown what fitness consequences, if any, result from being parasitized by *Hannemania* mites. Heavily parasitized specimens had swollen hands and feet compared to individuals with low parasite loads and such swelling might decrease locomotor performance. Decreased locomotor performance has been shown to have negative fitness consequences in other anuran species (Goater et al. 1993). Additionally, mites can cause hypersensitivity reactions and transmit rickettsiae and lethal viruses to hosts (Van der Geest et al. 2000). Sladky et al. (2000) suggested that diseases transmitted by *Hannemania* mites may have contributed to the early death of captive *Hyla arenicolor*. Further work is needed to evaluate whether diseases play a role in the coevolution of *Hannemania* and *E. marnockii*.

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THE AMPHIBIANS AND REPTILES OF
CAMP MAXEY, LAMAR COUNTY, TEXAS WITH
COMMENTS ON CENSUS METHODS

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Abstract.—Biological surveys provide information important to developing successful management strategies. Monitoring techniques can, however, be biased and studies on the optimal methods to use for different organisms are useful. Amphibians and reptiles were surveyed using several techniques at Camp Maxey, a 2570 ha. Army National Guard training site located in Lamar County, Texas. A total of 5009 individuals were recorded representing 44 species, ten of which were previously unreported for the county. Visual encounter surveys were the most effective method for surveying amphibians and reptiles for both abundance and diversity; however, other techniques were necessary for certain species, i.e., call surveys for anurans. Results also suggest that the experience of the surveyor is critical.

Surveys play an important role in understanding geographic differences and shifts in communities over time (Wilson & McCranie 2004; Lips 1999). Biological monitoring provides base-line data, allows for demographic study and monitoring of ecosystems and contributes to the understanding of ecological traits such as habitat preferences and seasonal activity at the species level (Dickman 1987; Petranka et al. 1993; Schlaepfer & Gavin 2001). Such information plays a critical role in developing successful management and conservation strategies for threatened and endangered species, and for protecting habitat from degradation (Gibbons & Strangel 1999).

Amphibians and reptiles have been acknowledged as good indicator species for habitat quality (Burton & Likens 1975; Wake 1991) because their physiological functions are often influenced by environmental conditions such as temperature, moisture, and pollutants (Schiefflin & de Queiroz 1991; Christy & Dickman 2002). In addition, they are relatively easy to survey and comparatively high in diversity (Burton & Likens 1975). Amphibians and reptiles are

also constituents of most communities, and so are important for healthy ecosystems (Soule & Wilcox 1980; Wilson 1985; Primack 1993). They function in food webs at all levels, from detritivores and herbivores to high level carnivores (Duellman & Trueb 1994; Dupuis et al. 1995). Because of their abundance, amphibians and reptiles can be crucial prey for arthropods, other amphibians and reptiles, birds, and mammals (Zug et al. 2001). However, herpeto-aunal surveys must be accurate to be useful and recent studies have suggested that census techniques are not equally effective (Ryan et al. 2002).

Amphibians and reptiles have been sampled by various methods including visual encounter surveys (Foster & Hampton 2003), sampling cover items (Fitch 1987), drift fences (Lewis et al. 2000), audible surveys (Lips 1999), the use of aquatic (Ryan et al. 2002) and basking traps (Shively & Jackson 1985), and road driving (Seigel 1986). Few studies have employed multiple techniques, and thus the effectiveness of the various techniques is rarely compared. In a study in South Carolina, different collection methods resulted in different subsets of the total herpetofauna being sampled (Ryan et al. 2002). Therefore, in developing monitoring methodology for specific amphibians and reptiles, one needs to know which collection methods will be optimal in that habitat and how accurately those methods depict the community assemblage.

The objective of this project was to describe the species diversity and abundance of amphibians and reptiles at Camp Maxey, in Lamar County, Texas. Much of this installation is Post Oak Savannah habitat and Blackland Prairie, both of which are endangered ecosystems (Kopachena & Kollar 1999). Quantitative survey data for amphibians and reptiles in these ecosystems are lacking and records for this county are scarce (Dixon 2000). This survey was conducted as a baseline for long-term monitoring by the Army National Guard. Additionally, this study compared the various collection techniques in ease of use and success in sampling for a wide variety of amphibians and reptiles.

STUDY AREA

Camp Maxey is a 2570 ha. Army National Guard Training site located just west of Powderly in Lamar County, northeast Texas. The northern border is defined by Lake Pat Mayse and the eastern boundary is Highway 271. The facility was established during World War II and environmental impacts since that time have been the result of training of Army personnel.

The vegetation at Camp Maxey consists of plants of the Oak Woods and Blackland Prairie ecosystems (Farquhar et al. 1996). About 65% of the installation (1657 ha.) is post oak/black hickory woodland dominated by post oak (*Quercus stellata*), black hickory (*Carya texana*), southern red oak (*Q. falcata*), and blackjack oak (*Q. marilandica*) with an understory of dogwood (*Cornus florida*) and farkleberry (*Vaccinium arboreum*). Little bluestem indiagrass (*Schizachyrium scoparium*) covers approximately 18% (462 ha.) of the installation where prescribed burning has controlled the encroachment of trees. Shortleaf pine forest is sparse, covering only about 3% (80 ha.) of the area in small scattered plots. The shortleaf pine (*Pinus echinata*) is the dominant tree with oaks and hickories common in the understory. Streamside trees are characterized by water oak (*Q. nigra*) and elms (*Ulmus alata* and *U. americana*).

A wetland inventory of Camp Maxey in 1998 indicated approximately 60 ha. of regulated water bodies, including streams, ponds, lakes and small wetlands (Gravett et al. 1999). Five lakes and a number of small ponds comprise about 33.2 ha. and have about 72 km of perennial tributaries.

MATERIALS AND METHODS

Several census techniques were used and records were collected at least three days a month from June 2002 to October 2003. Visual encounter surveys (VES), which involved random searches and turning ground cover in the various habitats, and surveys for

basking turtles and snakes at ponds and streams, were conducted each visit. Active trapping occurred in several of the aquatic habitats using unbaited minnow traps set in shallow areas along the shoreline of ponds and marshes, and baited (sardines or cat food) hoop and box turtle traps. Aquatic habitats were also dip-netted each trip and occasionally sampled with a large seine. Ten pairs of wood and tin cover items (each approximately 70 by 120 cm) were placed at eight sites (Fitch 1987; Grant et al. 1992). These 160 cover items were checked at least once each day that surveyors were present at the study area. Captured individuals were not marked, but animals found under the same cover item during sequential days were recorded as only one individual. Anurans were sampled by listening for breeding aggregations and by searches along the shores of aquatic habitats. The abundance of individuals in large choruses was estimated (Heyer et al. 1994). The main road in the site and various side roads were driven two nights each month at 10 mph for three hours beginning at dusk.

Because of the large number of animals captured, it was neither time-efficient nor practical to measure and mark every captured individual. With the exception of one voucher for each species, all animals were immediately released at the point of capture. The voucher specimens were deposited in the University of Texas at Arlington's amphibian and reptile collection (Fontenot et al. *in press*). The total number of each species collected by each method was tabulated for comparative purposes.

RESULTS

An estimated 5009 animals were recorded representing 44 species, including 5 salamanders, 13 anurans, 8 turtles, 7 lizards, and 11 snakes. Amphibians comprised over 92% of the censused herpetofauna community. Of the anurans, *Acris crepitans* was the most abundant (ca. 1250) while *Notopthalamus viridescens* was the most abundant salamander (ca. 53) (Table 1). Individuals of *Trachemys scripta* were the majority of the turtles censused (ca. 65). For the lizards, *Sceloporus undulatus* and *Scincella lateralis*

comprised 65% of the sampled community with approximately 41 individuals each. The pit-viper, *Agkistrodon piscivorus*, was the dominant species in the snake assemblage with 56 censused animals (Table 2).

Most of the anurans (72.9%) were documented from audible cues. Visual encounter surveying (turning logs) was the most productive method for collecting salamanders (Table 1). The best survey technique for semi-aquatic turtles was trapping, followed by visual basking surveys (66.4% and 31.9%, respectively). For *Terrapene carolina*, the only terrestrial turtle species found during the study, visual encounters and road driving were similarly effective (56.2 % and 43.8%, respectively). The majority of lizards and snakes were captured during VES (54.8% and 40%, respectively; Table 2).

DISCUSSION

This study found 5 species of salamanders, 13 anurans, 8 turtles, 7 lizards, and 11 snakes at Camp Maxey. Ten species had not been previously recorded for the county (Tables 1 & 2) (Fontenot et al., *in press*). This represents 54% of the species expected from known geographic ranges (Dixon 2000). Lamar County is at the edge of the eastern range of some species and the western extent of others so the numbers expected from distributions may have been unrealistic. As is common in assemblages of organisms, some species at Camp Maxey were quite abundant while many were rare and represented from only one or two specimens. Indeed, it is often suggested that the lack of some species in an area is likely due to dispersal problems (Magurran & Henderson 2003). Both ecological and historical aspects of the local environments are involved in species presence. Thus, size and composition of the site being surveyed are important considerations when evaluating the results of a general survey. A landscape approach to species richness is rarely considered in herpetofaunal collections because studies are often conducted in relatively small areas. Camp Maxey, although dominated by Post Oak Savannah and Blackland Prairie, is a large

Table 1. A comparison of the effectiveness of amphibian collecting techniques conducted at Camp Maxey, Lamar County, Texas.

Species	Search	Netting	Minnow Trap	Road Driving	Cover items	Calls	Total
Salamanders							
<i>Ambystoma maculatum</i> *	7	0	0	0	1	0	8
<i>Ambystoma opacum</i>	0	0	0	0	1	0	1
<i>Ambystoma texanum</i>	2	0	2	0	0	0	4
<i>Notophthalmus viridescens</i> *	16	2	4	1	0	0	23
<i>Siren intermedia</i> *	0	11	18	0	0	0	29
Total salamanders	25	13	24	1	2	0	65
Anurans							
<i>Acris crepitans</i>	539	50	0	37	0	624	1250
<i>Bufo velatus</i> *	3	0	0	52	0	603	658
<i>Gastrophryne carolinensis</i>	0	0	0	0	0	35	35
<i>Hyla cinerea</i>	4	0	0	17	0	691	712
<i>Hyla chrysocelis</i> :versicolor	30	0	0	11	0	222	263
<i>Pseudacris triseriata</i> †	15	0	2	17	0	379	413
<i>Rana areolata</i> *	0	0	0	1	0	0	1
<i>Rana catesbeiana</i>	220	0	43	34	2	474	773
<i>Rana clamitans</i>	21	1	0	7	0	26	55
<i>Rana palustris</i>	3	0	2	4	0	2	11
<i>Rana sphenoccephala</i>	40	0	4	101	1	209	355
Total anurans	875	51	51	281	3	3265	4526
Total amphibians	925	64	75	282	5	3265	4591

* Indicates a new record for Lamar County, Texas.

† Indicates a site record only.

Table 2. A comparison of the effectiveness of reptile collecting techniques conducted at Camp Maxey, Lamar County, Texas.

Species	Search	Minnow Trap	Turtle trap	Road Driving	Cover items	Total
Turtles						
<i>Apalone spinifera</i>	1	0	1	0	0	2
<i>Chelydra serpentina</i> †	1	0	1	1	0	3
<i>Graptemys pseudogeographica</i>	1	0	0	0	0	1
<i>Kinosternon subrubrum</i>	1	0	2	0	0	3
<i>Pseudemys concinna</i>	8	0	16	1	0	25
<i>Sternotherus odoratus</i>	0	0	17	0	0	17
<i>Terrapene carolina</i>	9	0	0	7	0	16
<i>Trachemys scripta</i>	25	0	40	0	0	65
Total turtles	46	0	77	9	0	132
Lizards						
<i>Cnemidophorus sexlineatus</i>	3	0	0	2	1	6
<i>Eumeces fasciatus</i>	10	0	0	0	15	25
<i>Eumeces laticeps</i>	4	0	0	0	4	8
<i>Hemidactylus turcicus</i> *	4	0	0	0	0	4
<i>Ophisaurus attenuatus</i> *	0	0	0	0	1	1
<i>Sceloporus undulatus</i>	33	0	0	0	8	41
<i>Scincella lateralis</i>	15	0	0	2	24	41
Total lizards	69	0	0	4	53	126
Snakes						
<i>Agkistrodon contortrix</i>	0	0	0	2	2	4
<i>Agkistrodon piscivorus</i>	24	1	0	29	2	56
<i>Coluber constrictor</i>	2	0	0	5	12	19
<i>Diadophis punctatus</i>	3	0	0	0	6	9
<i>Elaphe guttata</i>	2	0	0	1	0	3
<i>Elaphe obsoleta</i>	2	0	0	2	5	9
<i>Lampropeltis calligaster</i>	0	0	0	0	1	1
<i>Nerodia erythrogaster</i>	9	1	0	4	2	16
<i>Nerodia fasciata</i>	2	1	0	1	6	10
<i>Nerodia rhombifer</i>	9	0	0	2	0	11
<i>Thamnophis proximus</i>	11	0	0	3	19	33
Total snakes	64	3	0	49	44	160

site with a variety of other habitats including pine forests, various aquatic habitats, and disturbed areas. Some of these smaller areas produced records of the rarer species and so the assessment of survey method includes comments related to specific habitats.

One of the goals was to determine the relative effectiveness of particular sampling methods for inventorying amphibians and reptiles at Camp Maxey. This study found that the most effective technique overall was the VES, which accounted for 45% of the total reptiles and 47% of the total amphibians, and captured more of the total species than any other technique. Cover items were effective for some lizards and snakes, particularly at edges of forests. They also increased the ease of capture of some of the more elusive species, i.e., western ribbon snakes and yellow-bellied racers. Call surveys were effective for anurans but obviously did not record any other amphibians or reptiles. Road driving produced fewer numbers, but recorded most of the species except for some of the aquatic salamanders and turtles. Aquatic trapping (minnow and turtle traps combined) was fairly effective for turtles and aquatic amphibians.

As noted above, the VES method recorded 35 of the 44 amphibian and reptile species present, more than any other collecting technique. Additionally, except for the audible surveys, VES resulted in the most censused individuals (61.6 %). However, VES may be of limited usefulness in monitoring programs due to wide variations in the number of animals seen per unit time among observers. Indeed, some behavioral characteristics of individual species directly impact sampling accuracy. For example, nocturnal, cryptic, or wary animals may be missed by less experienced surveyors. In addition, it was found that some habitats could not be surveyed effectively by VES, i.e., some aquatic habitats, dense forests, and prairies. Training of personnel may reduce such potential sampling errors, but some bias would still be difficult to control.

Cover items, while less successful overall, accounted for many of the individual lizards and snakes captured. Additionally, because the number of cover items is a constant, statistical comparisons among habitats can be made. Seasonal variation was particularly apparent with this technique, with many of the records occurring from March to May. Minnow and turtle traps also sampled a limited range of species. For example, minnow traps only collected aquatic salamanders, larval amphibians, and semi-aquatic snakes. Like coverboards, minnow traps collect different species in different seasons, i.e., amphibians in the winter and snakes in the summer. Again, comparison of effort between habitats is easily evaluated with traps.

Call surveys obviously are necessary to effectively sample anurans, but like VES these are affected by the experience of the surveyor and are also dependent upon weather conditions. Weather also plays a significant role in road driving success, as only species that are moving are recorded. Both driving speed and visual acuity of observers also impact this technique.

Some of the techniques were more effective in specific habitats. Aquatic traps were, of course, used only when water was present but placement in appropriate microhabitats, i.e., next to logs or along banks, affected their success. Cover items also produced different results in different habitats. For example, in wetlands they quickly facilitated capture of both amphibians and reptiles, but in prairies they were much less effective. They were also quite successful in ecotones. Therefore, it is suggested that it is important to employ a variety of collection techniques for a period of time until it is known which is effective in each habitat.

An important aspect in evaluating a survey is to determine the reasons for the rarer and missing species. In this study, there were several species that were expected based on current geographic ranges (Dixon 2000) but not found during the survey. Some of these are uncommon or difficult to find, such as Texas horned

lizards and hognose snakes. It is suggested that sampling bias could influence the ability to record rare species. The survey at Camp Maxey was conducted through two summers and one winter with experienced herpetologists. It was expected that the majority of the species would be located, especially with the multiple collecting techniques. Therefore, it is concluded that results are an accurate reflection of most of the amphibian and reptile species present on the site. Amphibians and reptiles are vulnerable to a wide variety of environmental problems (Zug et al. 2001) and a number of anthropogenic effects from the military exercises that occur on the site could have extirpated local populations. However, when one examines the particular species that are missing it is noted that many are on the periphery of their geographic ranges. Random processes such as probability of dispersal into the area and local extinction due to small numbers would be expected to be involved in their occurrence at Camp Maxey. These factors may be major reasons for the low diversity on the site.

CONCLUSIONS

Conclusions from this study are that when surveying amphibians and reptiles, multiple census techniques should be used. These techniques should be designed with the local habitats in mind and attempts to evaluate the effectiveness of the methods should be made. Efforts to evaluate the causes of both the occurrence of abundant and rare species should include discussions of niche relationships and landscape level processes such as dispersal.

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EFFECTS OF AN INVASIVE GRASS
(*BOTHRIOCHLOA ISCHAEMUM*)
ON A GRASSLAND RODENT COMMUNITY

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Abstract.—The rodent assemblages in prairie dominated by native grasses and in prairie dominated by the exotic King Ranch bluestem (*Bothriochloa ischaemum*) in central Texas were compared to determine if non-native prairie supported a less species-rich rodent fauna than native prairie. Species richness was greatest in the native *Muhlenbergia* habitat (three species) and least in the non-native King Ranch bluestem habitat (one species). Densities of the hispid cotton rat (*Sigmodon hispidus*) were significantly greater in the *Muhlenbergia* habitat than in King Ranch bluestem. Relative abundance of *S. hispidus* correlated significantly with cover provided by dead material, *Muhlenbergia*, and by “other grasses” comprising a relatively small proportion of the prairie flora.

This study examined the small-mammal communities of several central Texas grasslands to assess the impact of introduction of an exotic grass, King Ranch bluestem (*Bothriochloa ischaemum*), on structure of the rodent community. King Ranch bluestem, native to Mediterranean Europe and the steppes of northern Asia (Correll & Johnston 1970), was introduced at Texas A&M experiment stations as a livestock forage grass (Silveus 1933). By the 1950s, old fields throughout the Edwards Plateau were extensively planted with this exotic grass (Riskind & Diamond 1988). In Texas and Oklahoma, *B. ischaemum* and related Old World bluestem grasses have been sown onto >1 million hectares of marginal farmland (White & Dewald 1996). Within Texas, King Ranch bluestem is found widely in several of Gould's (1975) vegetation areas: Gulf Prairies and Marshes, Post Oak Savanna, Blackland Prairie, Cross Timbers and Prairies, South Texas Plains, and Edwards Plateau. With such an extensive presence in Texas and Oklahoma, the introduction of King Ranch bluestem has the potential of influencing the small-mammal community over a broad region.

Other rodent-community studies have shown that small-mammal diversity, richness and relative abundance are lower in pure stands of grass than in native prairies (Schwartz & Whitson 1987; Hayslett & Danielson 1994). Similar studies have shown that rodent diversity correlates positively with plant diversity and cover (Rosenzweig & Winakur 1969; Price 1978; Price & Waser 1984). The presence of one to several grass species along with a larger array of forbs increases the variety of microhabitats and resource base, facilitating coexistence among rodent species. Bowles & Copsey (1992) demonstrated that the overall relative abundance of small mammals was higher in stands of native grass than in stands of non-native grasses.

The sprawling habitus of King Ranch bluestem tends to overwhelm and eliminate native monocot and dicot species, resulting in large homogenous plots of the exotic grass. Differences in the rodent community were expected between areas colonized by exotic King Ranch bluestem and areas comprising more-nearly native prairie. It was hypothesized that prairie dominated by King Ranch bluestem harbors fewer native species of rodents than does native prairie. The population densities of rodent species were also expected to be lower in non-native than in native habitats.

MATERIALS & METHODS

Study site.—King Ranch bluestem dominates the prairie community in many places in central Texas, including Hill Country State Natural Area (HCSNA). HCSNA, comprising an area of 2,172 ha, straddles the border of southern Bandera and northern Medina counties, Texas, and is located about 16 km southwest of Bandera. HCSNA lies within the Edwards Plateau vegetation zone (Gould 1975) and the Balconian biotic province (Blair 1950). This region is characterized by shallow soils underlain by limestone or caliche. Land use is primarily rangeland, with farming limited mainly to the deeper soils near rivers and associated valleys.

Three principal vegetation types intermingle in the region: mixed mesophytic forest in the moister riparian and canyon settings and, in drier situations, grasslands and Madrean evergreen woodlands (Amos & Gehlbach 1988). Woody habitats found at HCSNA include the Ashe juniper/oak, plateau live oak/midgrass, Texas oak, and pecan/sugarberry associations (Texas Parks and Wildlife 1998). The grassy habitats occur mainly in the openings within the upland juniper/oak and plateau live oak/midgrass associations where the principal grass species may be either native (little bluestem, *Schizachyrium scoparium*; silver bluestem, *Bothriochloa saccharoides*; sideoats grama, *Bouteloua curtipendula*; muhly grass, *Muhlenbergia* sp.), or non-native (King Ranch bluestem), or a mixture thereof. Muhly grass occurs primarily in low-lying drainage areas. Most of the gamagrass (*Tripsacum dactyloides*)/switchgrass (*Panicum virgatum*) association, once prevalent along West Verde Creek at HCSNA, has been converted to pasture dominated by King Ranch bluestem and to cultivated fields; narrow strips of this habitat remain sporadically along the creeks.

Sampling.—Rodents were trapped in Sherman live traps (7.6 by 8.9 by 33.0 cm) set in 11 transects of 30 traps in four grassland habitats: little bluestem ($n = 4$ transects), King Ranch bluestem ($n = 3$), *Muhlenbergia* ($n = 2$), and switchgrass/gamagrass ($n = 2$). Traps were placed approximately 5 m apart and were baited with crimped oats mixed with peanut butter. Each rodent captured was identified to species; except for a few individuals kept as voucher specimens, rodents were released unmarked near the site of capture. Sampling was conducted on 24 – 28 May, 28 June – 1 July, 16 - 19 August, 29 October - 1 November, 13 - 16 December 1999, and 10 - 14 February and 24 - 27 April 2000. Not all transects were established until the third sampling session. Therefore, the various habitats were not equally sampled, although every transect was sampled during each season. Transects were trapped for two consecutive nights.

Vegetation surveys were performed along all transects on the same days as rodent sampling. Ground cover was described and quantified following a modification of Daubenmire (1959) used in previous studies of small-mammal communities (Wilkins 1995; Hanchey & Wilkins 1998; Scales & Wilkins 2003). A vegetation sampling station was established within 1 m of every 5th, 10th, 15th, 20th, and 25th rodent trapping station. Cover provided by each vegetation class was assessed at various heights above the soil surface. The following vegetation classes were evaluated: dead material, forbs, King Ranch bluestem, little bluestem, *Muhlenbergia* sp., switchgrass, eastern gamagrass, sideoats grama, Texas grama, other grasses, and woody vegetation. Dead material was assessed at 5, 10, 25, and 50 cm above the ground. Forbs were assessed at 5, 10, and 25 cm. All grasses were assessed at 10, 25, and 50 cm. Woody vegetation was assessed cumulatively at 1 m and above. Each vegetation class was assigned a value from 0 to 6, based on the estimated amount of cover provided: 0 = 0% cover, 1 = 1-5%, 2 = 6-25%, 3 = 26-50%, 4 = 51-75%, 5 = 76-95%, and 6 = 96-100%. Values used in analyses were midpoints of these percentage ranges: code 1, 3%; 2, 15.5%; 3, 38%; 4, 63%; 5, 85.5%; 6, 98%.

Analyses.—Using the Statistical Analysis System (SAS Institute 1985), descriptive statistics were obtained for each vegetation class for each transect during each sampling session. Species richness, the total number of rodent species present, was determined for each habitat. For each rodent species and habitat, the number of individuals captured on all transects of that habitat was summed over the entire study period. From these sums, the relative abundances of individual rodent species were determined for each habitat as the number of individuals captured per 100 trapnights (Hanchey & Wilkins 1998; Schwartz & Whitson 1987); this was a means of addressing the unbalanced sampling design. These relative abundances of rodents were compared using the nonparametric Kruskal-Wallis test to elucidate any differences between stands of King Ranch bluestem and the native prairies (JMPIN 1997; Zar

1984). The Tukey-Kramer Honest Square Difference multiple comparison test was used to determine where differences in mean abundance, if any, lay (Zar 1984). Regression analyses (standard least squares; JMPIN 1997) of rodent densities against each vegetation category were undertaken to determine habitat preferences.

RESULTS

Vegetation analysis.—Non-native grassland settings at HCSNA are dominated by King Ranch bluestem. Cover in the non-native prairie was predominantly dead material provided by King Ranch bluestem, followed by living components of this species. Dead material at 5 cm averaged 42.5% to 58.7% coverage. Dead material at 10 cm and 25 cm was also substantial, but less than that found at 5 cm. Values for dead material at 10 cm averaged between 28.7% and 47.7%, and at 25 cm averaged between 6.3% and 14.3%. Coverage by dead material at 50 cm averaged only 1.3%. The vast majority of live grassy cover was provided by King Ranch bluestem, averaging 11.3% to 28.2% at 10 cm and 16% to 19.4% at 25 cm. King Ranch bluestem coverage at 50 cm was small (< 4.3%) for all three transects in all months. Forb cover in the King Ranch bluestem habitat was quite sparse, never exceeding 5% during any month for any height sampled. Amount of cover provided by “other grasses” also was small: Texas grama averaged < 1% coverage and values for other grasses at any height measured never exceeded 7.5% for any month.

Transects in the little bluestem association were sparse in overall vegetative cover. Dead material predominated in this habitat type at heights of 5 cm and 10 cm (averaging 22.2% to 29.8% at 5 cm, 7.4% to 20.4% at 10 cm), but substantially less dead material was found at greater heights of 25 cm and 50 cm. Little bluestem at 10 cm averaged at most 8.7% coverage and at 25 cm averaged $\leq 4.7\%$ coverage. Forbs and sideoats grama were similar in coverage, never averaging > 5% coverage. The “other

grasses” category also formed a minor component of this habitat, averaging $\leq 2.8\%$ coverage at 10 cm. Woody vegetation was present on three of the four little bluestem transects, but averaged $\leq 11.9\%$ coverage.

The two *Muhlenbergia* transects were dominated by dead *Muhlenbergia* sp. and by the living components of this grass. The tall stature of this grass resulted in large amounts of both dead and living material at 25 cm and 50 cm. Amounts of dead material at 5 cm, 10 cm, and 25 cm remained fairly constant throughout the study, averaging 43.5% at 5 cm, 43% at 10 cm, and 32% coverage at 25 cm. Dead material at 50 cm averaged 9%. Forb coverage never exceeded 6% at any height for any month. The “other grasses” category was a minor component of this grassland setting, averaging $< 8\%$ coverage at all heights sampled. Cover provided by King Ranch bluestem was exceedingly low, providing $< 1\%$ cover on one transect and none on the other.

The two switchgrass transects were characterized by dense switchgrass with lesser amounts of eastern gama grass. Dead material was primarily provided by switchgrass. The amounts of dead material provided by switchgrass were fairly constant for all months and similar for the heights of 5 cm and 10 cm, averaging 30% and 28%, respectively. Dead material averaged 14.5% to 18.2% at 25 cm and 7.2% to 11.4% at 50 cm. Most of the living herbaceous material was switchgrass, followed by forbs, then eastern gama grass. Switchgrass coverage averaged between 9.5% and 16%. Forb coverage averaged between 3% and 6.2%. Eastern gama averaged between 2.4% and 6% coverage. Woody vegetation above 1 m was present on both transects and averaged between 4% and 11.4% coverage for all months. Live King Ranch bluestem was also present occasionally on both transects; values for this grass at 5 cm and 10 cm averaged as high as 5.6% and as low as 0.4%. “Other grasses” on these two transects offered 6% coverage at 5 cm, 4% at 10 cm, and $< 2.5\%$ at 50 cm.

Rodent analysis.—Total sampling effort along these 11 transects at HCSNA was 2,970 trapnights in four habitats. The total catch was 117 rodents of four species, for a relative abundance of 3.94 individuals per 100 trapnights. A total of 870 trapnights along transects in King Ranch bluestem yielded 19 individuals of only one species, the hispid cotton rat (*S. hispidus*, 2.18 individuals per 100 trapnights). A total of 1,200 trapnights in the little bluestem habitat yielded two species, two *S. hispidus* (0.17 individuals per 100 trapnights) and eight *Peromyscus pectoralis* (white-ankled mouse, 0.67 individuals per 100 trapnights). In the switchgrass/gamma grass habitat, 300 trapnights yielded 15 *S. hispidus* (5 per 100 trapnights) and six *P. pectoralis* (2 per 100 trapnights).

Habitat dominated by *Muhlenbergia* sp. was the most species-rich habitat sampled, an effort of 600 trapnights yielding 67 individuals (11.2 individuals per 100 trapnights) of three species: *Sigmodon hispidus* (57 individuals, 9.5 per 100 trapnights), the fulvous harvest mouse (*Reithrodontomys fulvescens*; seven individuals, 1.17 per 100 trapnights), and Taylor's pygmy mouse (*Baiomys taylori*; three individuals, 0.5 per 100 trapnights). This is the only habitat in which *R. fulvescens* and *B. taylori* were captured.

Sigmodon hispidus was the only rodent species to occur in all four habitats and was the only rodent species included in statistical analyses because of the rarity of the other three species. A non-parametric Kruskal-Wallis test revealed a significant difference in *S. hispidus* densities ($X^2 = 9.06$, $df = 3$, $P = 0.029$) among the four habitats. The Tukey-Kramer HSD multiple comparison test showed that densities of *S. hispidus* were significantly greater ($P \leq 0.05$) in *Muhlenbergia* habitat than in King Ranch and little bluestem settings. Density of *S. hispidus* in the *Muhlenbergia* habitat was more than three times that in the King Ranch bluestem.

Regression analyses of *S. hispidus* densities with cover revealed eight categories of vegetation as significant ($P < 0.015$) positive

correlates of cotton rat densities. Dead material from assorted grasses and forbs were significant components of cover at 25 cm ($r^2 = 0.768$, $P = 0.0002$) and at 50 cm ($r^2 = 0.495$, $P = 0.0107$). Cover provided by *Muhlenbergia* at all sampled heights was significant: at 10 cm ($r^2 = 0.729$, $P = 0.0004$), at 25 cm ($r^2 = 0.750$, $P = 0.0003$), at 50 cm ($r^2 = 0.630$, $P = 0.0020$). The "other grasses" category also was significant at all heights: at 10 cm ($r^2 = 0.469$, $P = 0.0141$), at 25 cm ($r^2 = 0.503$, $P = 0.0098$), at 50 cm ($r^2 = 0.571$, $P = 0.0045$).

Densities of cotton rats did not vary predictably with cover provided by King Ranch bluestem ($P \geq 0.3589$), little bluestem ($P \geq 0.1213$), silver bluestem ($P \geq 0.4298$), Texas grama grass ($P \geq 0.1860$), sidecoats grama grass ($P \geq 0.2500$), eastern gamagrass ($P \geq 0.6440$), or switchgrass ($P \geq 0.5675$). Cover provided by forbs also was not significant for cotton rats at 5 cm ($r^2 = 0.098$, $P = 0.3218$), at 10 cm ($r^2 = 0.237$, $P = 0.1085$), at 25 cm ($r^2 = 0.147$, $P = 0.2186$).

DISCUSSION

It was predicted that the rodent community of prairie settings dominated by exotic King Ranch bluestem would demonstrate lower species richness than native prairie settings. Population densities of rodents were also expected to vary with the quantity and quality of vegetative cover. Results of the study demonstrated several of these expected differences.

Relative abundances of *S. hispidus* were highest in native *Muhlenbergia* and switchgrass, followed by non-native King Ranch bluestem habitat and, interestingly, even lower abundance in native little-bluestem habitats. This low relative abundance in little bluestem habitat likely reflected sparse vegetative cover resulting from prescribed burns during the previous year. There was a positive relationship of densities of *S. hispidus* in native prairie with increases in litter, *Muhlenbergia*, and "other grasses". Although *S. hispidus* occurred consistently in the King Ranch

bluestem habitat, their abundance was not significantly correlated with cover from the living component of this exotic grass. Yet, *S. hispidus* was positively correlated with dead material, derived principally from King Ranch bluestem; it is likely that the cover provided by litter from King Ranch bluestem is what *S. hispidus* found attractive. *Sigmodon hispidus* was also positively correlated with the “other grasses” category at 10 cm. Although the “other grasses” category at 10 cm was minor ($\leq 10\%$ coverage), it is possible that the added diversity of monocots presents a broader resource base needed by *S. hispidus*.

The Hill Country of Texas historically comprised relatively open savanna. Since the mid-1800s, there has been a general increase in the amount of woody cover as a result of fire suppression (Fonteyn et al. 1988) and the introduction of intensive grazing practices (Riskind & Diamond 1988). The impact of overgrazing already was evident at the turn of the century when Vernon Bailey (1905) and his federal agents conducted their biotic survey of Texas (Schmidly 2002). The suppression of fire and the confined grazing by cattle have encouraged the increase of Ashe juniper (*Juniperus ashei*), so that much of the Hill Country now includes dense stands of this evergreen tree (Fowler & Dunlap 1986). What remains of the original prairie is now a disjunct patchwork of prairie habitats ranging from tall-grass remnants in the eastern portion of the plateau to mixed-grass prairie in the central plateau to short-grass prairie in the more-arid western plateau (Riskind & Diamond 1988). Prior to 1860, Bandera County was considered to be intermediate in woody and grassy coverage, with slightly more than half of its area comprising grassy habitats (Weniger 1988). It is likely that an even larger proportion of this county is now covered in woody vegetation.

In addition to fragmentation, the prairie of the Edwards Plateau also faces threats from the establishment of exotic grass species, such as King Ranch bluestem examined in this project. Previous research regarding the effects of exotic grasses on floral succession

and community dynamics suggests that microhabitat and environmental conditions are affected by alien grass colonization (D'Antonio & Bartolome 1984, Vitousek 1990). Exotic grasses often add greatly to the litter layer, reducing water loss from soil and affecting temperature fluctuations by insulation (Facelli & Pickett 1991). These conditions often lead to the establishment of the exotic grass at the expense of native grasses (Evans & Young 1970). Further, the increased litter depth associated with exotic grasses increases the frequency and intensity of fires (Brown & Minnich 1986). The combination of these disturbances often leads to change in the local community and possibly to overall ecosystem change.

The establishment of King Ranch bluestem might present a threat to the rodent community at the study site and beyond. The expanded distribution of this grass threatens to further simplify the remaining patches of prairie on the Edwards Plateau, resulting in a prairie ecosystem drastically different than the native prairie. Concomitantly, the rodent communities might be altered to include fewer species, different species, or to have the same species represented in different proportions than in native habitats. Based on the findings of this project, land managers and conservationists should implement control practices that limit the distribution and spread of King Ranch bluestem.

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GENERAL NOTES

ENDOPARASITES OF HURTER'S SPADEFOOT,
SCAPHIOPUS HURTERII AND PLAINS SPADEFOOT,
SPEA BOMBIFRONS (ANURA: SCAPHIOPODIDAE),
FROM SOUTHERN OKLAHOMA

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The anuran family Scaphiopodidae (formerly Pelobatidae) is comprised of three genera and 11 species distributed throughout North America, Europe, and central Asia (Zug et al. 2001). In Oklahoma, four species within two genera are found in various parts of the state (Bragg 1944; 1965a). Two of these, Hurter's spadefoot (*Scaphiopus hurterii*) and the plains spadefoot (*Spea bombifrons*) are medium-sized toad-like frogs that are rarely seen because of their reclusive nature. This study follows Powell et al. (1998), Duellman & Sweet (1999), and Collins & Taggart (2002) in recognizing the former as a full species and not a subspecies of the eastern spadefoot, *Scaphiopus holbrookii* (cf. Conant & Collins 1998).

Although information is available on the ecology of these two anurans (Bragg 1965b; Wasserman 1968), little is known about their parasites (Rodgers 1941; Brooks 1976). One possible reason for this paucity of information is, unlike other anurans, these toads are explosive breeders, usually only coming out of underground burrows following torrential rainfall. This study presents data on some endoparasites of these two taxa from southern Oklahoma.

On the evening of 23 April 2004, a torrential rainfall event occurred in southern Oklahoma (Marshall County) in the vicinity of the University of Oklahoma Biological Station (33° 52.6'N, 96° 48.1'W). A total of 14 adult *S. hurterii* (seven males, seven

females, 59.4 ± 5.6 , range 49-69 mm snout-vent length [SVL]) and three adult (one male, two female, 53.7 ± 8.1 , 45-61 mm SVL) *S. bombifrons* were collected by hand for parasitological examination. Specimens were placed in plastic bags on ice and returned to the laboratory within 24-48 hr for necropsy. Toads were euthanized with a dilute Chloretone[®] (chlorobutanol) solution and the entire gastrointestinal tract (including the liver, spleen, and gall bladder), lungs, coelomic cavity, urinary bladder, and reproductive organs were examined for protozoan and helminth parasites. Blood smears were taken from the exposed heart and stained with DifQuick[®]. Feces from the rectum was collected and placed in individual vials containing tap water supplemented with antibiotic (100 I. U./mL penicillin-G 100 µg/mL streptomycin) and examined directly without sucrose flotation by light microscopy for coccidia. Protozoans were fixed in warm Schaudinn's solution, stained with Gomori trichrome, and mounted in Permount[®]. Intact cestodes were relaxed in cold tap water overnight, transferred to 70% ethanol for fixation, stained with acetocarmine, and mounted entire in Canada balsam. Free metacestodes from the coelomic cavity were fixed in 70% ethanol and prepared as whole mounts by staining in acetocarmine, dehydrating in ethanol, clearing in methyl salicylate, and mounting in gum damar. Tissues containing metacestodes was fixed in 10% neutral buffered formalin, embedded in Paraplast[®], sectioned at 10 µm, stained in hematoxylin and eosin, and mounted in gum damar. Nematodes were placed in a drop of glycerol on microscopic slides and identifications were made from these temporary mounts.

Helminth voucher specimens were deposited in the United States National Parasite Collection (USNPC), Beltsville, Maryland, USA as follows: *Mesocestoides lineatus* (USNPC 95218, 95221), *Cosmocercoides variabilis* (USNPC 95219), *Oswaldocruzia pipiens* (USNPC 95220). Host voucher specimens were deposited in the Arkansas State University Museum of Zoology (ASUMZ 28795-28808).

Eight of 14 (57%, five male, three female) *S. hurterii* harbored infections, including two protozoans, one cestode, and two nema-

todes; two of three (67%) of the *S. bombifrons* were infected with a cestode species (Table 1). Five (36%, four males, one female) of the *S. hurterii* harbored multiple infections of protozoans and helminths. None of the toads of either species harbored trematodes, hematozoa in the blood, or coccidian oocysts in the feces.

Brandt (1936) previously reported several *Opalina* sp. from *S. holbrookii* from North Carolina. The opalinid protozoan, *Protoopalina mitotica* has been reported previously from the New Mexico spadefoot (*Spea multiplicata*) from El Paso County, Texas (Delvinquier et al. 1995). This current study reports *P. mitotica* from *S. hurterii* and Oklahoma for the first time.

The ciliate protozoan, *Nyctotherus cordiformis*, is a cosmopolitan parasite of frogs and toads and, while it is not surprising that *S. hurterii* was found to be infected with this species, this is, to the author's knowledge, the first time this parasite has been reported from Oklahoma. Brandt (1936) previously reported *N. cordiformis* from the related eastern spadefoot (*S. holbrookii*) in North Carolina. In the adjacent states of Arkansas and Texas, this ciliate has been reported from various frogs and toads of the families Bufonidae, Hylidae and Ranidae (McAllister 1987; 1991; McAllister et al. 1989; 1993; 1995a).

Although the cyclophyllidean cestode, *Mesocestoides* sp. has been reported from various amphibians and reptiles, its complete life cycle still remains an enigma. This tapeworm, reported previously as *Mesocestoides* sp. or *M. lineatus* has been found in a variety of anurans of the families Bufonidae, Hylidae, and Ranidae from Arkansas, Iowa, Michigan, Minnesota, New York, South Dakota, Texas, and Wisconsin (McAllister & Conn, 1990; McAllister et al. 1995a; 1995b; Gilliland & Muzzall 1999; Muzzall et al. 2001). However, this study reports the parasite from *S. hurterii* and *S. bombifrons* and, most importantly, the family Scaphiopodidae for the first time. Brandt (1936) previously reported proteocephalid "cysts" from *S. holbrookii* from North Carolina.

Table 1. Endoparasites of *Scaphiopus hurterii* and *Spea bombifrons* from Marshall County, Oklahoma.

Host/Parasite	Location in host	Prevalence ^a	Intensity ^b
<i>Scaphiopus hurterii</i>			
Protista			
<i>Protoopalina mitotica</i>	rectum	3/14 (21%)	b
<i>Nyctotherus cordiformis</i>	rectum	3/14 (21%)	b
Cestoidea			
<i>Mesocostoides lineatus</i>	liver, coelom, mesenteries	3/14 (21%)	b
Nematoda			
<i>Cosmocercoides variabilis</i>	rectum	1/14 (7%)	8 ± -
<i>Oswaldocruzia pipiens</i>	small intestine	4/14 (29%)	3.8 ± 4.2 (1-10)
<i>Spea bombifrons</i>			
Cestoidea			
<i>Mesocostoides lineatus</i>	liver, coelom, mesenteries	2/3 (67%)	b

^aNumber infected/number examined (percent).^bIntensity = mean ± 1SD (range) or impossible to quantify.

Metacestodes recovered from spadefoot hosts represent non-proliferating tetrathyridia of *M. lineatus* (Fig. 1a). All cestodes were fully invaginated and had a typical deep invagination canal (Fig. 1b) opposite a normal excretory pore. Histological sections (Figs. 1c & 1d) show all the classic hallmarks of standard non-proliferating tetrathyridia (i.e., solid parenchyma in hindbody, unarmed arostellate tetra-acetabulate scolex). Host reactions varied between parasites, and ranged from mild to heavy inflammation to fibrotic encapsulation (Fig. 1c).

The ascarid nematode, *Cosmocercoides variabilis* is a relatively common roundworm of anurans. This parasite (as *Oxysomatium* sp.) has been reported previously from bullfrogs, *Rana catesbeiana* from Oklahoma (Trowbridge & Hefley 1934) and many other amphibians (McAllister & Bursey 2005). Brandt (1936) reported *C. dukae* (= *C. variabilis*) from *S. holbrookii* from North Carolina.



Figures 1. (a). Free tetrathyridia of *M. lineatus* removed from coelomic cavity of *Scaphiopus hurterii*. (b). Whole mount of unstained tetrathyridium showing deep invagination canal (arrow). Scale bar = 100 μ m. (c). Photomicrograph of three encapsulated tetrathyridia in liver showing host inflammation and capsules (arrows). Scale bar = 500 μ m. (d). Higher magnification of encapsulated tetrathyridium in liver tissue showing prominent scolex (arrow) and solid hindbody parenchyma (asterick). Scale bar = 250 μ m.

The trichostrongylid nematode, *Oswaldocruzia pipiens* is another common nematode of anurans (McAllister et al. 1995b). Most notably, it has been reported previously from Woodhouse's toad, *Bufo woodhousii woodhousii*, the southern leopard frog, *Rana sphenocephala utricularius* and *R. catesbeiana* from Oklahoma (Trowbridge & Hefley 1934), and Couch's spadefoot, *S. couchii* from Arizona (Goldberg & Bursey 1991), and *S. holbrookii* from North Carolina (Brandt 1936). This study reports this nematode from *S. hurterii* for the first time.

In summary, this study reports six new host and two new geographic records for these spadefoot toad parasites. However, it is suggested that a more complete survey on *S. bombifrons* be conducted, including a larger sample size and examination of various specimens from other parts of their range.

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INDEX TO VOLUME 57 (2005)
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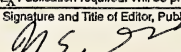
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