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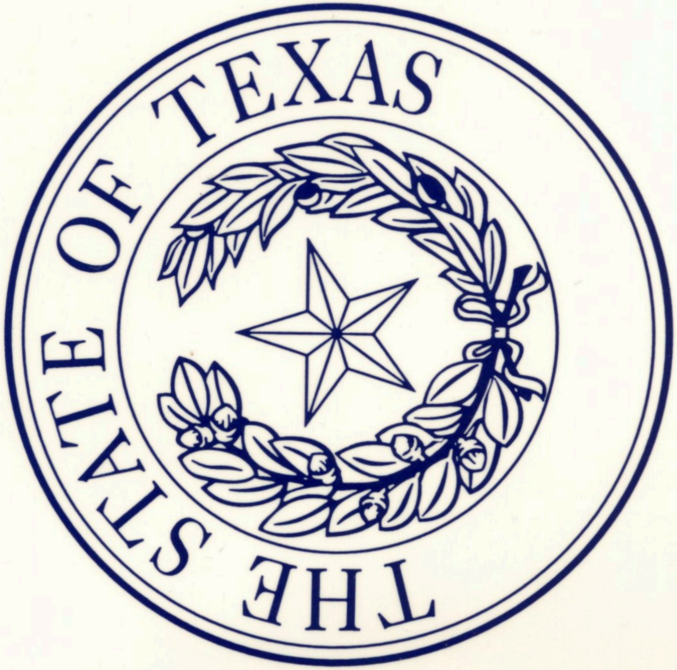

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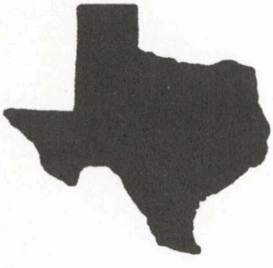

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CONTENTS

Reproductive and Hematological Effects of Feeding Diets Containing Gossypol to Mature Ewes

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ABSTRACT

The objectives were to determine what effects the short- or long-term feeding of diets containing gossypol to mature ewes had on reproductive and hematological variables. In Exps. 1 and 2, 29 Rambouillet ewes (avg wt, 128 ± 3.2 lb) and 35 Western white-face ewes (avg wt, 102.4 ± 3.6 lb), respectively, were randomly assigned to diets containing: (A) no cottonseed products (n = 10, 12); (B) cottonseed meal and cottonseed hulls (n = 9, 11); or (C) whole cottonseed and cottonseed hulls (n = 10, 12, respectively). Ewes were fed 3.3 lb hd^{-1} d^{-1} of their respective diet for either 87 ± 3.9 d (Exp. 1) or 126 ± 5 d (Exp. 2). Free gossypol (FG; Exp. 1) or total gossypol (TG; Exp. 2) intake for diets A, B, and C were: 0, 0; 0.95, 2.87; and 2.42, 3.14 g d^{-1}, respectively. Embryos were surgically flushed from the oviducts of superovulated ewes 5 d post-estrus (d 0 = estrus). Blood samples were taken from each ewe near the end of each experiment and serum hemoglobin and osmotic fragility of erythrocytes (RBC) were determined. Experimental data were analyzed by ANOVA and orthogonal polynomials. Controlled feeding of cottonseed products showed no effect ($P > 0.05$) on ADG, estrous cycle length, interval to onset of estrus after synchronization, number of ovulations after superovulation, number of embryos recovered, quality score of embryos, or percentage of abnormal embryos. Serum hemoglobin increased in a linear fashion ($P < 0.005$, Exp. 1) and a quadratic fashion ($P < 0.001$, Exp. 2) as FG or TG intake increased, respectively. Erythrocyte hemolysis increased in a linear manner ($P < 0.001$, Exp. 2) as TG intake increased. Feeding cottonseed products to mature ewes resulted in no detrimental effects on reproductive variables measured. However, hematological evidence indicated that fragility of RBC increased as gossypol intake increased.

KEYWORDS: embryo, erythrocyte fragility

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Gossypol, a yellowish phenolic compound, is a toxic constituent of pigments in the roots, stems, leaves, and seeds of cotton plants. In Texas and southern sections of the United States, cottonseed products represent an abundant source of feed ingredients for the diets of ruminant animals. During the fall and winter months when range forages are in short supply, animals used for reproductive purposes are often fed supplemental diets which may contain cottonseed hulls as a source of roughage and(or) cottonseed meal or whole cottonseed as a source of protein.

Studies have indicated that gossypol has detrimental effects on humans (Qian and Wang, 1984), laboratory animals (Lin et al., 1980), non-ruminants (Skutches et al., 1974), and ruminants (Arshami and Ruttle, 1988, 1989). When fed in large quantities, signs of gossypol toxicity include anorexia, reduced growth rate, and labored breathing (Randel et al., 1992). More important in domestic farm animals is the antifertility effects of gossypol on males. Bulls and rams seem especially susceptible to gossypol, causing decreased fertility because of serious damage to the gonadal tissues. Lumen diameter, wall thickness, number of cell layers in the seminiferous tubules, and size of Leydig and Sertoli cells are reduced in males fed diets containing gossypol when compared to tissues from control males (Arshami and Ruttle, 1988, 1989; Kramer et al., 1989). Monogastric females are also sensitive to the antifertility effects of products containing gossypol. Estrous cycles, pregnancy, and early embryonic development all appear to be disrupted by gossypol (Randel, 1991). However, few studies have been reported that specifically investigate the effects of gossypol on female reproduction in ruminants. Using Rambouillet ewes, Kuhlmann et al. (1993) investigated the effects of feeding dietary supplements containing soybean meal, expander solvent (ES) cottonseed meal (CSM), and direct solvent (DS) CSM on selected reproductive characteristics. No differences were observed in ovulation rates, pregnancy rates, lambing rates, or birth weights of lambs from ewes consuming gossypol for a 16 wk period. In a study using Brangus heifers, Wyse et al. (1991a) found that the daily consumption of 5 g of free gossypol (FG) from CSM reduces ($P < 0.005$) the number of follicles > 4 mm in diameter when compared to heifers consuming 15 g FG daily from whole cottonseed (WCS) or control heifers consuming 0 g FG (32, 85, and 98 follicles, respectively). In a different experiment using the same treatments and similar animals, Wyse et al. (1991b) reported that heifers consuming CSM produce more ($P < 0.06$) degenerative embryos (33.3%) when compared to animals consuming WCS (13.9%). However, there were no observed differences in degenerative embryos when comparing control heifers to those consuming WCS. The objectives of the present experiments were to study the effects of short- or long-term feeding of diets containing gossypol on selected reproductive characteristics and hematology of red blood cells in mature ewes.

MATERIALS AND METHODS

Experiment 1

Twenty-nine Rambouillet ewes (avg wt, 128 ± 3.2 lb) were randomly assigned to one of three treatment diets containing: no cottonseed feed ingredients (control, n = 10), cottonseed meal and cottonseed hulls (CSM/CSH, n = 9), and whole cottonseed and cottonseed hulls (WCS/CSH, n = 10; Table 1). Treatment diets contained 11.7% crude protein as determined by proximate analysis (AOAC, 1990) and were formulated to be isocaloric and isonitrogenous to meet or exceed NRC requirements (NRC, 1975). Ewes were offered water *ad libitum* and fed 3.3 lb per hd of their respective diet daily.

Table 1. Composition of diets.

Ingredient[†]	Diet		
	Control	CSM/CSH	WCS/CSH
	--------	%	--------
Sorghum, dry rolled	26.78	26.78	26.78
Cottonseed hulls		48.15	39.94
Sudangrass hay[‡]	53.31		
Cottonseed meal		16.32	
Whole cottonseed			29.92
Soybean meal	10.50		
Fat, animal and(or) vegetable	6.05	5.39	
Urea	0.71	0.71	0.71
Salt	0.50	0.50	0.50
Ammonium Chloride	0.50	0.50	0.50
Dicalcium phosphate	0.89	0.89	0.89
Potassium chloride	0.07	0.07	0.07
Trace mineral premix[§]	0.50	0.50	0.50
Vitamin A, D, and E[¶]	0.19	0.19	0.19

†Dry matter bases, except whole cottonseed as fat source.

‡Ground with a tub grinder and mixed with other ingredients daily at feeding.

§Provides: 13.2 ppm Mn, 36 ppm Zn, 19.8 ppm Fe, 3.9 ppm Cu, 0.9 ppm I, 0.6 ppm Co, and 60 ppm Mg.

¶Provides: 540 IU per lb Vitamin A, 68 IU per lb Vitamin D, and 6 IU per lb Vitamin E.

Free gossypol percentage was determined by Pope Testing Laboratories, Dallas, TX. The results were: CSH, 0.045%; CSM, 0.258%; and WCS, 0.48% FG. By calculation, the ewes were offered the following amount of FG: control, 0 g d^{-1}; CSM/CSH, .95 g d^{-1}; and WCS/CSH, 2.42 g d^{-1}. Diets were fed for an average of 87 ± 3.9 d.

Estrous cycles were monitored daily using raddled rams equipped with marking harnesses. Weekly blood samples were obtained to monitor luteal function. Concentrations of serum progesterone were determined using a radioimmunoassay kit (Coat-A-Count TKPG5; Diagnostic Products Corp., Los Angeles).

After receiving their respective diet for an average of 68 d, ewes were synchronized by implanting one-half of a 6 mg Syncro-Mate-B (SMB) bovine implant (Sanofi Animal Health Corp., Overland Park, KS) subcutaneously in the ear as described by Ruttle et al. (1988). Synchronization implants were removed after 12 d.

Ewes were superovulated using a series of FSH-P injections (Schering Corp., Kenilworth, NJ) as follows: d 10 after implantation, 4 mg FSH-P b.i.d.; d 11, 3 mg FSH-P b.i.d.; and d 12, 2 mg FSH-P b.i.d. (total dose = 18 mg; Ruttle et al., 1988; Figure 1). After superovulation treatment and implant removal, the ewes were placed with rams equipped with a marking harness and mated naturally. A maximum of 3 ewes were placed with each ram during the breeding process. Breeding activity was observed at 12 hr intervals for 72 hr.

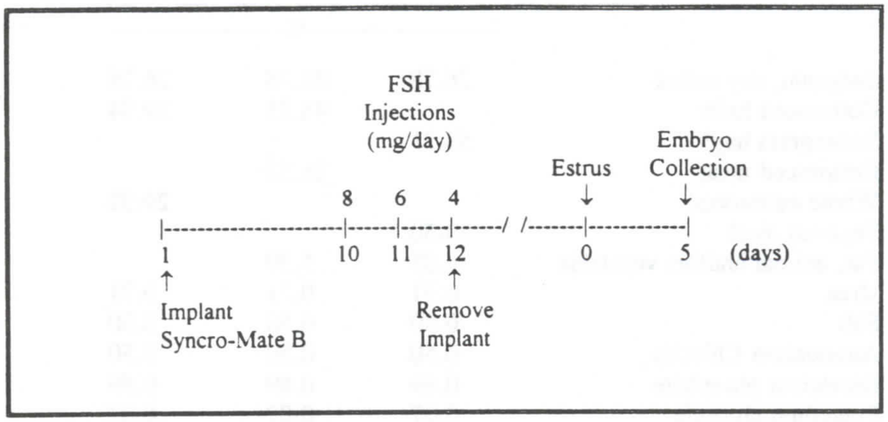

Figure 1. The synchronization and superovulation treatment plan for the ewes. The numbers below the dashed line refer to days of treatment. The dosages of FSH were divided equally between an a.m. and p.m. injection on d 10, 11, and 12.

Before breeding, the rams were fertility tested via electroejaculation and the semen evaluated for percent motility, normality, viability, live-dead, and concentration. Rams were fed diets that did not contain any cottonseed products and were not allowed access to any of the experimental diets.

Five days after estrus (estrus = d 0), the embryos were collected surgically via mid-ventral laparotomy. The number of corpora lutea (CL) on each ovary was counted and recorded. Embryos were flushed from each uterine horn using Dulbecco's phosphate buffered saline (American Embryo Systems, Grand Prairie, TX) containing 2% fetal calf serum (American Embryo Systems). Media flushed from each uterine horn was collected in a petri dish (Falcon Intergrid; Becton Dickinson & Co., Lincoln Park, NJ) and embryos were located under a stereomicroscope (Nikon, Japan). Evaluation of embryos was completed using a phase-contrast microscope (Leitz Fluovert, West Germany). Embryos were then classified on the basis of their morphological quality using a 5-point scale as follows: 1 = Excellent -- perfectly symmetrical with even granulation and no blastomere extrusion; 2 = Good -- occasionally slightly asymmetric in shape, even granulation with some blastomere extrusion; 3 = Fair -- slightly asymmetrical in shape, blastomere extrusion and some degeneration; 4 = Poor -- uneven granulation, much blastomere extrusion and degeneration; and 5 = Unfertilized.

After the ewes were on their respective diets for an average of 82.5 d (pooled SE = .85), a blood sample was obtained for analysis of serum hemoglobin. Serum was obtained from the samples via centrifugation, frozen, and stored at -20°C until analysis. Serum hemoglobin was determined using a Co-Oximeter (Model 282, Instrumentation Laboratories, Lexington, MA).

End points evaluated by statistical analysis were: ADG, estrous cycle length, interval to onset of estrus after synchronization, number of CL after superovulation, number and quality of embryos collected per ewe, and serum hemoglobin. Data were analyzed by a completely randomized design analysis of variance (Steel and Torrie, 1980) using the General Linear Models procedure (SAS, 1985). The two degrees of freedom for treatment were resolved into a set of orthogonal polynomials (linear and quadratic) based on the grams of FG fed per day.

Experiment 2

Experimental materials and methods were the same for Exp. 2 with the following exceptions. Thirty-five Western white-faced ewes (avg wt, 102.4 ± 3.6 lb) were randomly assigned to the three treatment diets. By analytical determination, the percentages of FG and total gossypol (TG) in the cottonseed products were: CSH, 0.02, 0.05%; CSM, 0.16, 1.04%; and WCS, 0.57, 0.64%, respectively. The percentage of FG and TG was determined by Dr. M. C. Calhoun, Texas A&M Agricultural Experiment Station, San Angelo, TX. By calculation, the ewes were offered the following amount of FG and TG: control diet, 0, 0 g d^{-1}; CSM/CSH diet, 0.55, 2.87 g d^{-1}; and WCS/CSH diet, 2.7, 3.14 g d^{-1}, respectively. Experimental diets were fed for an average of 126 ± 4.6 d.

After receiving their respective diet for an average of 107 d, the same synchronization and superovulation scheme as Exp. 1 was implemented (Figure 1). Surgical procedures for collection and evaluation of embryos were also the same as previously described.

After evaluation, the embryos were incubated in DAPI (4'-6'-diamidino-2-phenylindole; Sigma Chemical Co., St. Louis, MO) stain in the dark for 15 min and then observed under a microscope using epiflourescence filters (excitation, 520 nm; barrier, 580 nm; Zeiss, West Germany). Subsequently, the nuclear membrane of embryos that were dead or degenerating was penetrated by the DAPI stain, emitting a brilliant yellow-colored fluorescence.

On d 155 of the experiment, a blood sample was obtained from each ewe for analysis of serum hemoglobin as previously described in Exp. 1. Serum was obtained from the samples via centrifugation, frozen, and stored at -80°C until analysis. In addition, on d 298 of the experiment, a sample of whole blood was obtained for determination of erythrocyte (RBC) hemolysis. Red blood cell hemolysis was performed by Dr. M. C. Calhoun according to the procedures of Nelson (1979).

Statistical analysis was the same as Exp. 1 with the following exceptions. Percentage of abnormal embryos was analyzed by Chi-Square, and the two degrees of freedom for treatment were resolved into a set of orthogonal polynomials (linear and quadratic) based on the grams of TG fed per day.

RESULTS AND DISCUSSION

Results from Exp. 1 indicated that mature ewes fed cottonseed products containing gossypol for an average of 87 d had no effect on ADG (0.27 lb), length of first (15.4 d) or second (16.3 d) estrous cycle, concentration of serum progesterone (2.0 ng mL^{-1}, range = 0.3 to 6.4 ng mL^{-1}, data not shown in tabular form), interval to onset of estrus after synchronization (26.8 h), number of ovulations after superovulation with FSH-P (10.6 CL), number of embryos recovered by surgical collection (4.6 embryos), or quality score of embryos (2.6; Table 2). Similar results were found in Exp. 2 after feeding cottonseed products for an average of 126 d. Mature ewes fed a diet containing gossypol showed no differences in ADG (0.24 lb), interval to onset of estrus after synchronization (33.9 h), number of ovulations after superovulation with FSH-P (14.1 CL), number of embryos recovered by surgical collection (5.8 embryos), quality score of embryos (3.7), or the percentage of abnormal embryos as determined by DAPI stain (57.6 %; Table 3).

Table 2. Least-squares means for performance and reproductive characteristics in ewes fed cottonseed products for 87 days (Experiment 1).

	Diet			Pooled	
End point	Control	CSM/CSH	WCS/CSH	SE	P[†]
Free gossypol fed, g d^{-1}	0	0.95	2.42		
ADG, lb	0.29(10)[‡]	0.27(9)	0.24(10)	0.05	0.75
Estrous cycle length, d					
First cycle	15.4(10)	15.3(9)	15.4(10)	0.29	0.98
Second cycle	15.9(7)	16.2(6)	16.7(6)	0.52	0.57
Interval to onset of estrus after synchronization, h	31.2(10)	24.0(9)	25.2(10)	4.37	0.47
No. of ovulations after superovulation with FSH-P	9.3(8)	11.8(8)	10.7(10)	2.53	0.77
No. of embryos recovered	4.8(6)	5.4(7)	3.6(7)	1.54	0.68
Embryo quality score[§]	2.5(4)	2.8(3)	2.4(7)	0.55	0.89

†Probability of overall treatment difference.
‡Mean (No. of ewes).
§See Materials and Methods for explanation.

In agreement with these results, Kuhlmann et al. (1993) reported no differences in ovulation rates, pregnancy rates, lambing rates, or birth weights of lambs in Rambouillet ewes fed cottonseed supplements for 16 wk. With regard to embryo quality, Wyse et al. (1991b) found similar results in Brangus heifers where mean quality grade, developmental stage score, and viability index of embryos recovered nonsurgically at 7 d postestrus were not affected by dietary FG.

Table 3. Least-squares means for performance and reproductive characteristics in ewes fed cottonseed products for 126 days (Experiment 2).

End point	Diet			Pooled SE	P[†]
	Control	CSM/CSH	WCS/CSH		
Total gossypol fed, g d^{-1}	0	2.87	3.14		
ADG, lb	0.25(11)[‡]	0.22(11)	0.26(12)	0.04	0.79
Interval to onset of estrus after synchronization, h	33.3(9)	34.7(9)	33.8(11)	5.99	0.99
No. of ovulations after superovulation with FSH-P	11.8(8)	13.1(9)	17.3(11)	3.67	0.53
No. of embryos recovered	4.9(8)	4.2(9)	8.4(11)	2.36	0.39
Embryo quality score[§]	3.5(4)	4.1(4)	3.5(6)	0.54	0.68
Abnormal embryos, %	32.8(3)	75.0(4)	65.0(5)	18.06	0.32

†Probability of overall treatment difference.
‡Mean (No. of ewes).
§See Materials and Methods for explanation.

The only effects observed in these studies were the effects of feeding cottonseed diets on blood or serum characteristics. In Exp. 1, total hemoglobin ($P < 0.005$) increased in a linear fashion as the amount of FG fed per day increased (Figure 2). In Exp. 2, total hemoglobin ($P < 0.001$) increased in a quadratic manner as the amount of TG fed per day increased (Figure 3). Also in Exp. 2, hemolysis of RBC increased in a linear fashion ($P < 0.001$) as the amount of TG increased (Figure 4). Kuhlmann et al. (1993) also observed increased RBC osmotic fragility when feeding gossypol containing products to ewes. Erythrocyte fragility increased ($P < 0.01$) when the duration of feeding either ES or DS CSM increased from 6 to 16 wk, but RBC hemolysis was not affected by method of processing CSM (ES vs DS). These results are in agreement with those previously reported in cattle. Brangus heifers fed 5 g FG per day demonstrated an increased hemolysis of RBC at 42, 56, and 70 d of treatment when compared to heifers receiving less than 0.002 g FG per day (Wyse et al., 1991c). Increased concentration of plasma hemoglobin from ewes which consumed diets containing gossypol suggests that the feeding of cottonseed products increases the fragility of the outer membrane of red blood cells.

Therefore, based on the results of this study, diets containing cottonseed products fed for an average of 87 or 126 d in which the daily FG intake did not exceed 2.7 g or in which 65 to 70% of the diet contained cottonseed products had no detrimental effects on the reproductive characteristics observed.

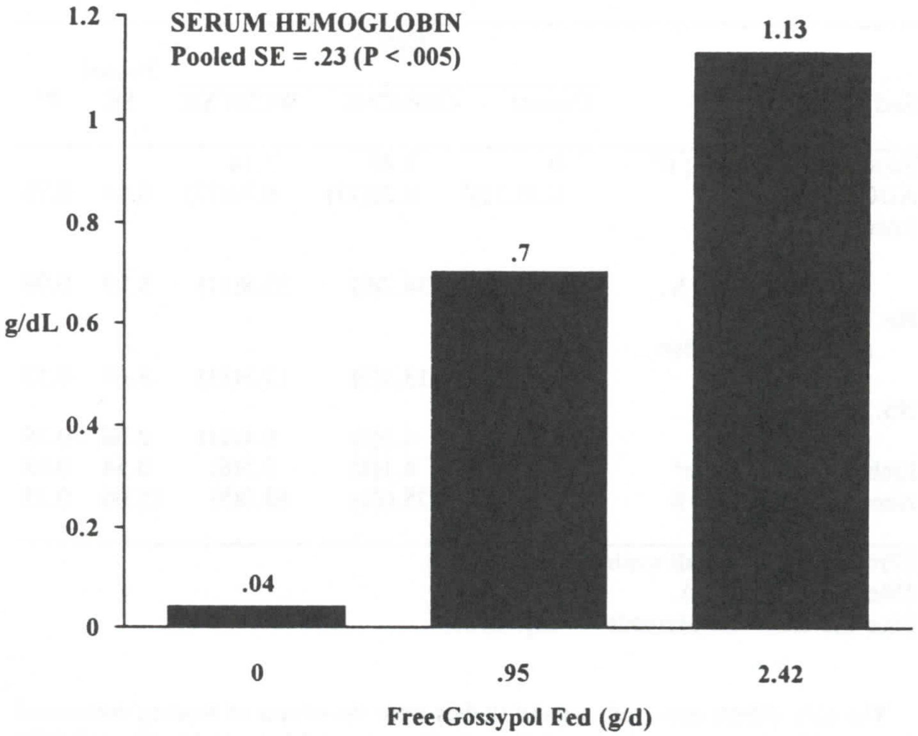

Figure 2. The effect of feeding cottonseed products (0 g FG, control diet; 0.95 g FG, CSM/CSH diet; and 2.42 g FG, WCS/CSH diet) to ewes on concentration of serum hemoglobin. The number of ewes that contributed to each mean were 8, 8, and 10, respectively.

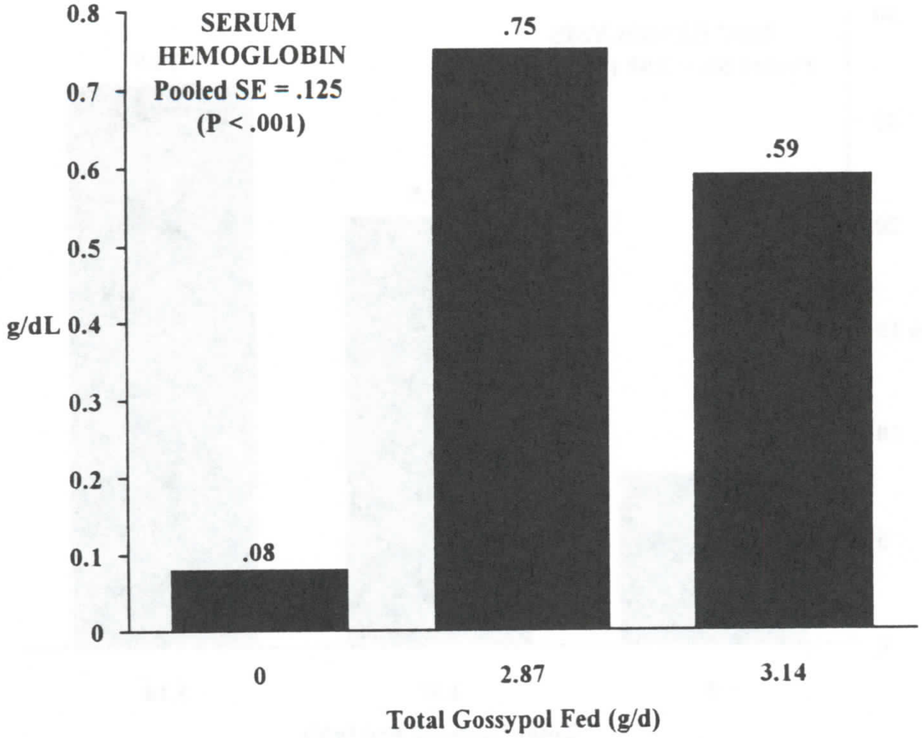

Figure 3. The effect of feeding cottonseed products (0 g TG, control diet; 2.87 g TG, CSM/CSH diet; and 3.14 g TG, WCS/CSH diet) to ewes on concentration of serum hemoglobin. The number of ewes that contributed to each mean were 10, 8, and 10, respectively.

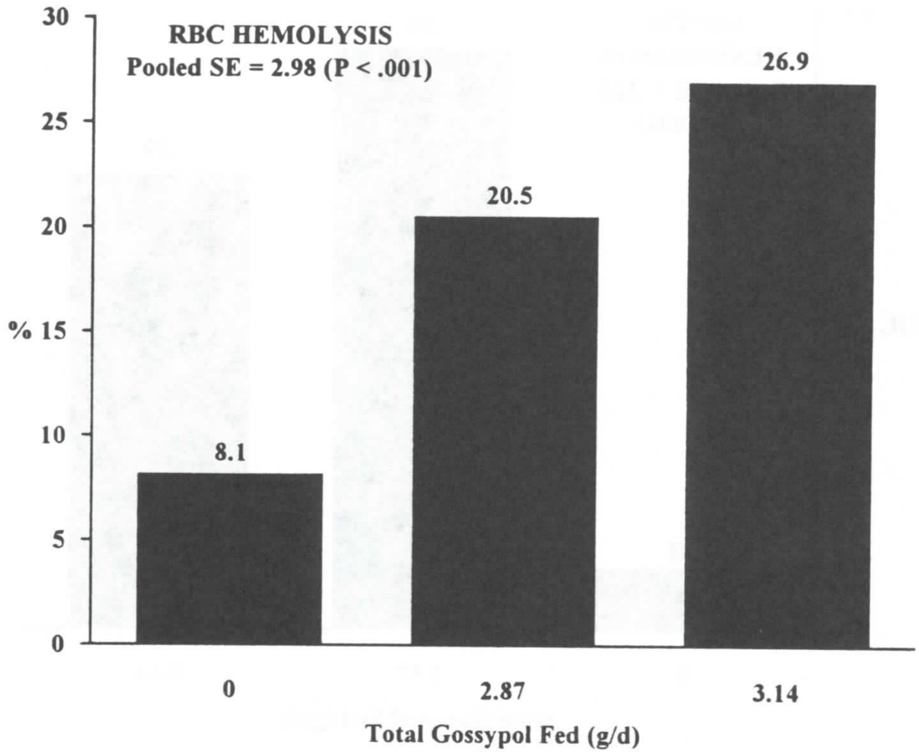

Figure 4. The effect of feeding cottonseed products (0 g TG, control diet; 2.87 g TG, CSM/CSH diet; and 3.14 g TG, WCS/CSH diet) to ewes on red blood cell hemolysis. The number of ewes that contributed to each mean were 10, 7, and 9, respectively.

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Spirochete Seroprevalence in Rodents of North Central Texas

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ABSTRACT

Prevalence of exposure to spirochetes, particularly *Borrelia burgdorferi*, in rodents of North Central Texas was determined using an indirect immunofluorescent assay. The Chi-square test was used to analyze positive sera reaction across season and tick distribution across rodent species. This test did not detect a seasonal significant difference of seropositive specimens ($X^2 = 2.45$, df = 3, $P > 0.05$). Percent tick infestation was significantly different across rodent species ($X^2 = 14.176$, df = 7, $P < 0.05$). Other data collected included 1) seasonal distribution of seropositive reactions in adult rodents, 2) distribution between trapsites of adult rodent positive serological reactions, 3) tick infestation organized by individual rodent stage and sex, 4) percent of each species seropositive, and 5) percent adult seropositive reactions per month.

KEYWORDS: *Borrelia burgdorferi*, *Peromyscus leucopus*, lyme disease

Lyme borreliosis, caused by the spirochete *Borrelia burgdorferi*, is a health hazard throughout the United States. Antibodies to *Borrelia burgdorferi* have been detected in mammals throughout the United States (Godsey et. al., 1987; Magnarelli et al., 1984b). Rodents, mainly mice, in different regions of the country have been infected with the spirochete (Anderson et al., 1987a; Loken et al., 1985).

There are three known geographic foci of lyme borreliosis in the United States: 1) New York-Connecticut area, 2) California, and 3) the Wisconsin area. *Peromyscus leucopus* has proven to be a major reservoir of the disease along the Atlantic coast of North America (Donahue et al., 1987; Levine et al., 1985; Mather et al., 1989) and also in the midwest portion of the United States (Anderson et al., 1987b; Godsey et al., 1987).

In Texas, research has been conducted on prevalence of *Borrelia* spirochetes in ticks (Teltow et al., 1991; Rawlings and Teltow, 1994) and seroprevalence of antibodies to *Borrelia burgdorferi* in horses (Cohen et al., 1992). Teltow et al. (1992) isolated spirochetes from four species of arthropods--three ticks and a flea. However, they were only able to culture spirochetes from 0.68% of pooled samples

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Julie Rawlings, Zoonosis Control Division, Texas Department of Health, Austin, provided the sera which was used as a positive control. Dr. Alan Barbour, University of Texas Health Sciences Center, San Antonio, provided the monoclonal antibodies used in this study. Dr. Jesse Cocke, Texas Agricultural Extension Service, Stephenville, assisted with identification of ticks. *Corresponding author.

of ticks and 1.4% of pooled flea samples. Rawlings and Teltow (1994) fared better, isolating spirochetes in 1.03% of individual adult *Amblyomma americanum* (L.)--the only tick found to harbor spirochetes during the course of their study.

Serological studies have been used to determine prevalence of *Borrelia* spirochete infection in mammals (Anderson et al., 1983; Magnarelli et al., 1984a, 1984b). A number of protocols for serological detection exist; one is the indirect immunofluorescent assay or IFA (Magnarelli et al., 1984b, 1984c; Russell et al., 1984). A disadvantage of this test is non-specificity. A positive reaction when using *B. burgdorferi* as the antigen for serum antibodies does not preclude the possibility of cross reaction if the mammal was exposed to another species of *Borrelia*.

Mammalian reservoirs of *B. burgdorferi* in Texas have not yet been determined. Cohen et al. (1992) reported that only 1 in 469 samples of horse serum collected from central Texas was positive for *B. burgdorferi* infection. If the epidemiology of the disease is similar to other areas of the United States, then rodents should be involved. It is likely that sylvatic mice, and possibly other small mammals are reservoirs of the disease in Texas. Thus, the objective of this study was to determine the prevalence of *Borrelia* exposure in native small mammals in North Central Texas.

MATERIALS AND METHODS

Selection of Subjects and Research Design

Trap areas were chosen to ensure sampling of *P. leucopus* (Schmidly, 1983). Rodents were trapped at six locations in North Central Texas (Fig. 1). Ten to twenty traps per site were open during the specified dates (reported below) except in inclement weather. Sympatric species trapped at these sites were also tested. Trapsite A was located seven miles east of Stephenville, Texas, in Erath County. This trapsite was sampled every month from 19 July 1989 until 19 July 1990. Trapsite B was located one mile northeast of Stephenville, Texas, in Erath County. Trapping was conducted from August through October 1989. Trapsite C was located six miles south of Weatherford, Parker County, Texas. Traps were set from September through November 1989, and in February and April 1990. Trapsite D was located two miles southeast of Stephenville in Erath County, Texas. This site was trapped from October through December 1989, and February, June, and July of 1990. Trapsite E was located one mile east of Stephenville, Texas, in Erath county. Traps were set from February through April, 1990, and again in June and July, 1990. Trapsite F was located 2 miles south of Hico, Texas, in Hamilton County. Traps were set during February and April of 1990.

Two types of live traps were used: Sherman live traps and a custom made, treadle variety. The Sherman live traps were 5.08 cm wide, 6.35 cm tall, and 16.51 cm long. The custom made traps were 5.08 cm wide, 6.35 cm tall, and 30.48 cm long. Bait consisted of either birdseed, oatmeal, sunflower fruits, dog food, or a combination of any of these. Collected specimens were given identification numbers that corresponded to the trapsite and held in individual cages with food and water until testing. All small mammals were identified to species. Specimen data also included date of capture, sex, life stage, and number of ticks present. Life stage was determined by fur texture and molt patterns.

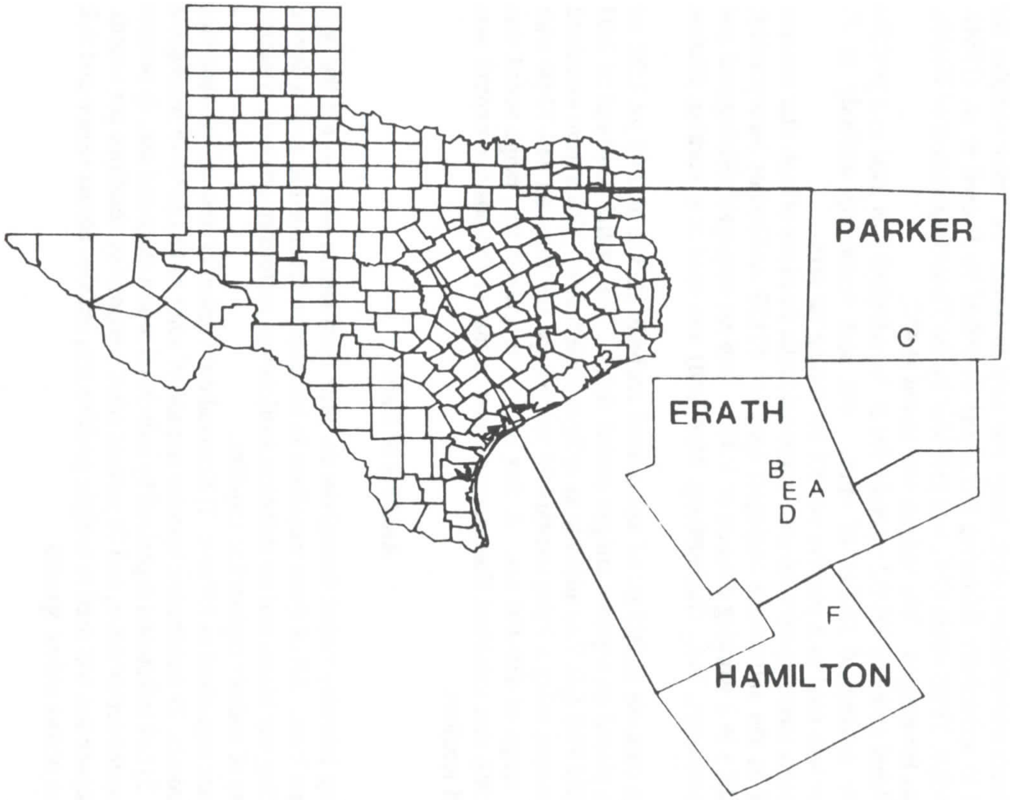

Figure 1. Trapsite locations in North Central Texas. One trapsite was located in each of Parker and Hamilton Counties, while four trapsites were in Erath County. All are designated with a capital letter in the approximate location within the county.

Preparation of Serum Samples

All dissections were conducted under a laminar flow hood with ultraviolet lights to minimize contamination of tissues. Dissection instruments were flame sterilized. Each specimen was killed by cervical dislocation and immediately bled. The blood was placed in a 1.5 ml microfuge tube, allowed to sit for 20 minutes to ensure clotting, and centrifuged at 2000 rpm (325 X G) for 10 minutes. The serum was aspirated using a sterilized capillary pipet and placed in another labeled microfuge tube. The tubes of sera were stored at -20°C.

Serological Studies

An indirect immunofluorescent assay was used to screen the serum samples for antibodies to spirochetes following techniques described by Russell at al. (1984). *B. burgdorferi*, Texas strain GW, was provided by the Texas Department of Health, and used as the antigen. The antigen was stored at 4°C.

Monoclonal antibody H5332 (specific for *B. burgdorferi*) was used as a positive control for serological studies of mice. Rat sera containing antibody to *B. burgdorferi* was used as a positive control for testing rat sera.

Fluorescein isothiocyanate labeled immunoglobulin fractions of high titer antisera were used as the anti-mouse conjugate (product #2150 Antibodies Incorporated; Davis, Calif.) in a working dilution of 1:400. Anti-rat conjugate (Kirkegaard and Perry Laboratories, Inc., Gaithersburg, Maryland) was used at a working dilution of 1:40.

Positive controls (0.003 ml of monoclonal antibody H5332 or 0.03 ml 1:32 rat sera) were placed on separate antigen coated slides. The control consisted of 0.03 ml of 0.03M PBS (pH 7.6) added to an antigen coated slide. Slides were examined for fluorescence using a Zeiss standard 16 microscope and filter set #48-77-09 with excitation range of 450-490 nm. A titer of 1:20 or greater (the range tested was 1:20 to 1:80) that exhibited fluorescence equal to that of the positive control was considered reactive.

Analysis of Data

Trapping intensity varied throughout the year from site to site, as did the type of traps and baits. All of these variations in techniques fluctuated to such a degree that sampling was biased and no statistical analysis was performed on data pertaining to numbers of rodents captured at trapsites.

Data were organized as follows: 1) Seasonal distribution of seropositive reactions in adult rodents, 2) distribution between trapsite of adult rodent positive serological reactions, 3) tick infestation organized by individual rodent stage and sex, 4) percent of each species seropositive, and 5) percent adult seropositive reactions per month. The Chi-square test was used to analyze positive sera reaction across season and tick distribution across rodent species.

RESULTS

Several species of mammals not listed in previous literature were shown to exhibit positive serological reactions. These species include *Baiomys taylori* (Thomas), *Peromyscus attwateri* (J. A. Allen), *Reithrodontomys fulvescens* (Allen), and *Reithrodontomys montanus* (Baird). At the time this study was conducted, *Sigmodon hispidus* (Say and Ord) had not been reported to exhibit a positive reaction, but Oliver et al. (1995) have recently characterized Lyme disease in this rodent species.

The seropositive rodents were captured in three different counties: Erath (10 positive), Parker (four positive), and Hamilton (four positive). Although *P. leucopus* had the greatest number of seropositive specimens, it did not have the highest percent of positive serological reactions. *R. montanus* demonstrated the highest percentage of positive serological reactions, but only six representatives of this species were collected and only one was seropositive.

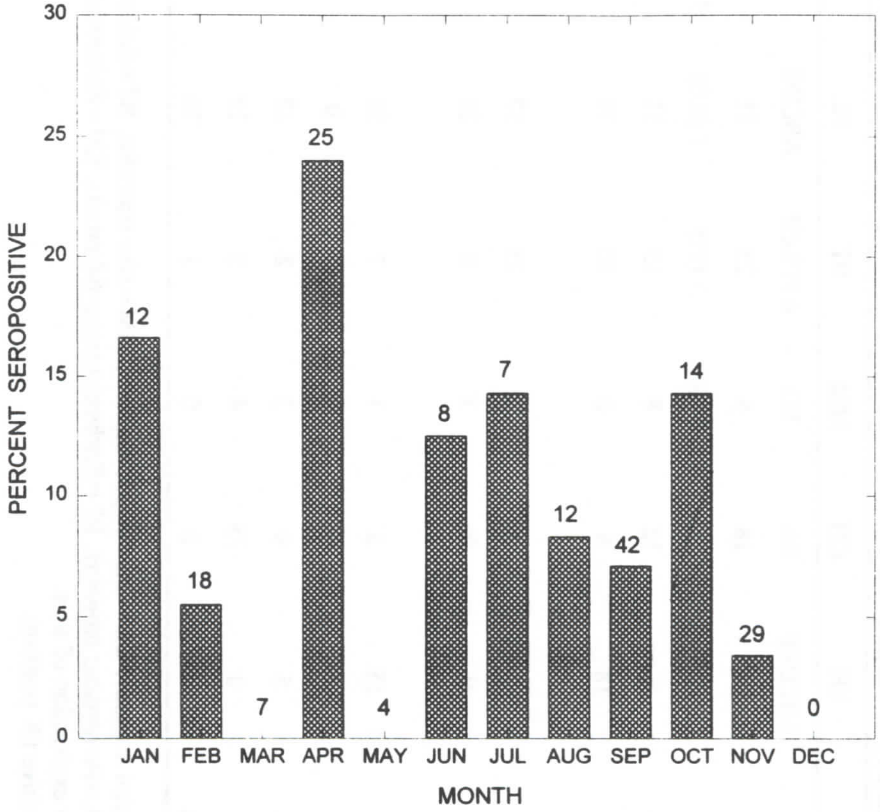

Figure 2. Adult sample size and percent seropositive rodents per month. Numerals above bars indicate sample size; bar heights represent the percent of seropositive specimens collected during the month. The data are grouped for all species of rodents tested during the month.

Table 1. Summary of trapping and biological data collected during study for each species of rodent tested.

Species†	SH	CH	MM	BT	PL	PA	RF	RM
Trap site‡	ABCDEF	BA	BD	ABCDEF	ABCDE	CA	ACEF	DF
# captured	24	18	8	25	81	24	28	6
# positive§	1 (4.2)	0 (0)	0 (0)	3 (12)	7 (8.6)	3 (12.5)	3 (10.7)	1 (16.6)
male	6	12	8	15	51	14	12	3
female	18	6	0	10	30	10	16	3
Stage								
adult	24	16	5	25	57	18	27	6
juvenile	0	2	3	0	24	6	1	0
Season								
autumn	15	3	1	7	31	2	7	2
winter	4	0	0	5	9	10	8	4
spring	5	0	3	8	22	6	13	0
summer	0	15	4	5	19	6	0	0
# with ticks	2	0	0	1	16	2	1	0

†SH=*Sigmodon hispidus*, CH=*Chaetodipus hispidus*, MM=*Mus musculus*, BT=*Baiomys taylori*, PL=*Peromyscus leucopus*, PA=*Peromyscus attwateri*, RF=*Reithrodontomys fulvescens*, RM=*Reithrodontomys montanus*.

‡See text for explanation of sites.

§Number positive (% positive).

The month of April had a larger percent (24%) of seropositive rodents than the other months of the year, which corresponds with adult population peaks in several rodents (Fig. 2). This is also an active time for nymphal and larval ticks of certain species to be foraging. During April, species that were seropositive included *P. leucopus* (one), *P. attwateri* (one), *R. fulvescens* (three), and *B taylori* (one). April was the only month during which more than one species was seropositive. There was no significant difference among seropositive specimens between seasons ($X^2=2.45$, df=3, $P>0.05$).

None of the 36 juvenile rodents in this study was seropositive. Fifteen of the 121 male rodents captured (12.3%) were seropositive, while 3 of 93 (3.2%) of the females were seropositive.

All ticks collected during the study were in nymphal or larval stages. Three species were identified - *Dermacentor variabilis* (Say), *Amblyomma americanum* (L.) and *Ixodes scapularis* Say. *D. variabilis*, *A. americanum*, and members of the genus *Ixodes* harbor *B. burgdorferi* (Anderson et al. 1983, 1985, 1986; Piesman and Sinsky, 1988; Rawlings et al., 1987; Anderson and Magnarelli, 1980).

Tick infestation was significantly different across rodent species ($X^2=14.176$, df=7, $P<0.05$), with the value for *P. leucopus* accounting for over half of the Chi-square value of 14.176. Species without ticks had values that only accounted for about one-fifth of this value. This suggests that percent tick infestation is biased by *P. leucopus*, and that there may be very little host preference in other rodent species. Of 36 juvenile rodents collected, 4 (11.1%) were infested with ticks. A total of 18 ticks were found on 178 adult rodents, a 10.1% infestation. When sorted by sex, 10 of 121 male rodents (8.3%) and 12 of 93 female rodents (12.9%) were infested with ticks.

DISCUSSION

Previous research from the three geographic foci of Lyme borreliosis implicated *P. leucopus* as a major reservoir of the disease. The percent of adult rodents that exhibited a serological reaction in this study (10.1%) is similar to the serological reactions of adult rodents in the midwest (6%) (Anderson et al., 1987b), although not as high as the percentages along the Atlantic Coast (17-50%) (Magnarelli et al., 1984b, 1984c).

Habits of the two families of rodents trapped during the study period were researched to determine chance of exposure to the tick transmitted spirochetes. Several factors, including habitat, activity, home range, and tick infestation seem to play roles in the possibility of exposure. The two species that had no specimens exhibiting a serological reaction were *Chaetodipus hispidus* (Baird) and *Mus musculus L.* Both species frequent areas not conducive to tick infestation. *C. hispidus* prefers dry habitats, where foraging ticks are less likely to be found. According to Dalquest and Horner (1984), parasites are almost never found on this species. Thomas et al. (1990) reported eight species of ectoparasites on *C. hispidus*, but none of them were ticks. *M. musculus*, with its close association to human habitations, could be exposed to areas that have been treated with acaricides, or other pest control. Although both species can be active year round, *C. hispidus* can also become inactive in winter and *M. musculus* has been known to inhabit man-made structures during that time. The home range of both of these species is particularly small. *C. hispidus* has a home range of 0.30 ha (Schmidly 1983) and *M. musculus* has a home range of only 0.23 ha (Waggoner, 1974). Schmidly (1983) also noted the sedentary behavior of these two species, which would decrease the likelihood of contact with an infected tick vector.

No ticks were found on *R. montanus*. This species prefers well drained, climax grasslands or blackland prairies, typically avoiding tall grass. These habitats are not ideal for foraging ticks. Dalquest and Horner (1984) noted that ectoparasites were seldom found on this species. The small sample trapped in this study did not have ectoparasites, but one specimen exhibited a positive serological reaction indicating possible contact with an infected vector. A larger sample size would have provided better data to test the relationship between *R. montanus* and possible tick vectors. All other species trapped use habitats conducive to tick infestation (tall grass, moist vegetation) and were active year round. Home ranges varied, but all were bigger than *C. hispidus* and *M. musculus*.

With the exception of *R. montanus*, species that exhibited a positive serological reaction also had specimens with tick infestation. Tick infested rodents harbored both larval and nymphal stages. In the case of Lyme disease, an infected mouse can pass *B. burgdorferi* on to the tick vector, which typically maintains the disease transtadially (Spielman et al., 1984). After molting, the adult tick vector can then feed on larger mammals, including humans.

Timing of exposure to spirochetes can affect the results of serological tests. *P. leucopus* exhibits an early IgM response followed by an IgG response (Schwan et al. 1989). The initial IgM response in *P. leucopus* can be detected as early as one to two days after infection. Schwan et al. (1989) demonstrated that the IgG1 and IgG2 response in *P. leucopus* increased during the 84 days of their experiment. Also, antibody response may differ with the rodent species tested.

Fifteen of the 18 positive serum reactions in the 214 specimens examined were male. This might indicate a higher susceptibility among males, or perhaps a prolonged antibody response. There are differences in the activity between males and females in several of the species assayed (Schmidly, 1983). If the males of the species were more active, they would be more likely to come in contact with foraging ticks, thus they would be more likely to become infected. In the current study, however, roughly equal percentages of males (10/122=8.9%) and females (12/93=12.9%) were infested with ticks.

The lack of seropositive reactions in juveniles may be attributable to their immunological incompetence. Golub (1977) determined that mice do not generate an antibody response until at least one week of age. Antibody response is not equal to that of an adult mouse until at least 3 weeks of age. Moody et al. (1990) experimentally infected rats with *B. burgdorferi* at one week of age. Two weeks after inoculation, antibodies were detected using an ELISA. Shih and Pollack (1992) determined that *B. burgdorferi* had to multiply locally in the skin for several days before becoming systemic, which might further complicate the antibody response in a young mouse.

The Chi-square detected randomness of positive serum reaction across season. Along the Atlantic Coast there is typically a peak of infection in rodents in the spring. Results of this study indicate that statistically there is no such peak in North Central Texas, possibly due to the warmer winters in Texas that allow ticks to remain active year round. Three species (*P. leucopus*, *P. attwateri*, and *B. taylori*) were trapped year round, and each had seropositive specimens. Year round activity could play a major role in spirochete maintenance, thus increasing the likelihood of susceptibility.

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Coyote Condition and Reproduction in Response to a Reduction in Population Density

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ABSTRACT

Four 5000-ha sites located in Andrews County, Texas, were studied during 1990 - 1992 to determine the effect of coyote (*Canis latrans*) population reduction on coyote physical characteristics, body condition, and reproduction. Seasonal coyote removal on two sites reduced coyote density from an estimated 0.12 to 0.06 coyotes km^{-2}. Coyote density remained stable on the other two sites throughout the study. Coyote removal did not create a change in coyote physical characteristics or body condition. Fetal sex ratios appeared to favor males at higher population densities. After about 9 months of coyote removal, a greater percentage of juvenile females from the experimental areas exhibited higher counts of corpora lutea and resorption placental scars. However, due to the higher resorption rate, juvenile females from the experimental areas minimally contributed to coyote population density. Adult female reproduction appeared unaffected by coyote removal.

KEYWORDS: *Canis latrans*, corpora lutea, fat, growth, removal

Coyote (*Canis latrans*) management programs typically involve some level of coyote population control (Balser, 1964; Beasom, 1974; Connolly, 1982). However, an understanding of coyote reproduction and fitness is necessary to formulate effective and ecologically sound management practices. Connolly and Longhurst (1975) examined the effect of control on coyote populations using a simulation model, and determined that a minimum annual removal of 75% was needed to consistently lower coyote density. A stimulated reproductive rate was one factor that created the need for such a high annual removal. This simulation model was based on work by Knowlton (1972) who found that the number of uterine swellings per female and litter size varied inversely with density in Texas coyotes. Also, the density of the coyote's principle prey species may be a partial determinant in coyote density and, therefore, be a casual mechanism on the coyote reproductive rate, both in terms of litter size and percentage of females breeding (Clark, 1972).

Mammalian body condition is commonly related to species fitness (Clutton-Brock et al., 1982). Coyote body condition has been observed to decline over winter

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(Todd and Keith, 1983). Adult male coyotes are known to be heavier and taller than females (Bekoff, 1977; Daniel, 1973). However, information is lacking concerning the relationship between body condition and population density. Therefore, our objectives were to assess changes in coyote physical characteristics, body condition, and reproduction on areas of stable and declining coyote population densities in western Texas. This investigation was conducted jointly with a study of the ecological impacts of coyote removal (Henke, 1992).

MATERIALS AND METHODS

The study was conducted between April 1990 and January 1992 in Andrews County, Texas. An expanded account of the study area and coyote densities is in Henke (1992). Four areas, approximately 5000 ha each, were chosen for study. Two areas in northeastern Andrews County served as the experimental areas where coyotes were removed seasonally, and the other two areas, in southern and western Andrews County, respectively, served as the comparison areas where only a limited number of coyotes were removed. To avoid ambiguity, the areas on which coyotes were controlled were referred to as experimental areas because coyote "control" was the treatment, whereas the areas that received no treatment were referred to as comparison areas. Coyotes were seasonally collected (April, July, October, and January) by aerial shooting. Complete coyote removal was attempted on the experimental areas, whereas five coyotes were collected from each comparison area each season. All coyotes were immediately retrieved and processed in the field.

Coyote relative abundance for each area was estimated by scent station lines as outlined by Roughton and Sweeney (1982). Scent station lines were conducted twice seasonally on the experimental areas, one week immediately before and one week immediately after aerial shooting. A synthetic W-U lure attractant gel (Fagre et al., 1983) was used as the scent throughout the study. Coyote populations on experimental areas were estimated by the removal method (Zippin, 1958). Density was estimated by dividing the population estimate by the search area. Equations predicting coyote density from scent station relative abundance indices were developed using least-squares linear regression.

Upon collection each coyote was sexed and then weighed to the nearest 0.2 kg. Body length was measured along the dorsal surface from the nose to the base of the tail. Shoulder height was measured from the base of the communal pads to the dorsal border of the scapula. Ratio of palatal width to length of the upper molar tooth row was calculated according to Howard (1949) to verify each specimen as *Canis latrans*. As an appropriate index of fat deposits, the relative amount of mesentery fat and subcutaneous fat thickness measured at the hip, back, and ribs were visually rated using a subjective scale of 0 (none) to 3 (abundant).

A lower canine tooth was extracted from each coyote. Age was estimated by enumeration of cementum layers in microscopic sections of canine teeth (Linhart and Knowlton, 1967) by Matson's Laboratory (Missoula, MT). For statistical analyses of condition and reproductive parameters, coyotes were classified as juveniles ($<$ 1 yr) and adults ($\geq$ 1 yr).

Female reproductive tracts were excised and kept on wet ice until examined in the laboratory. Ovaries were placed in 10% formalin for 48 hours, washed in tap water, sliced into 1 mm sections, and the number of corpora lutea recorded. Uterine horns were cut longitudinally and the number of primary and resorption scars were recorded (Gier, 1968). If pregnant, the number of fetuses were recorded, the sex was determined for each fetus, and the crown-rump length was obtained as outlined by Kennelly et al. (1977). Reproductive parameters of females were separated by age class. Corpora lutea counts were averaged from females collected in April, July, and October.

The experiment was a completely randomized design with repeated measures. Differing coyote densities caused by coyote removal was the major treatment source of variation through time. A general linear model's analyses of variance was used to test the effects of treatment, season, and year on scent station relative abundances. A general linear model's analyses of variance was used to test the effect of treatment and year on coyote weight, length, shoulder height, age, relative fat indices, percent females breeding, number of primary and resorption placental scars, and number of corpora lutea. Multiple comparisons were made using mean separation when a significant ($P < 0.05$) interaction between treatment and year was noted (Cochran and Cox, 1957). Homogeneity of variances among treatments was tested by using Bartlett's test at $P < 0.05$ (Steel and Torrie, 1980). Distributions of appropriate residuals were tested using Shapiro-Wilk tests at $P < 0.05$. Log transformation ($\log_{10}$) of the data was performed when non-normal distributions of residuals occurred. Transformed data was retested to assure that the assumption of normality was met. Homogeneity of the differences of variances between effects was tested using sphericity tests (Geisser and Greenhouse, 1958). The Greenhouse-Geisser epsilon coefficient was multiplied by both effect and error degrees of freedom to yield the corrected F-value when sphericity was violated (BMDP, 1990). Sex ratios and adult:juvenile ratios were analyzed by the chi-square test.

RESULTS

Totals of 354 and 81 coyotes were removed from the experimental and comparison areas, respectively, from April 1990 to January 1992. Scent station indices were greater ($P = 0.024$) on comparison than experimental areas (Table 1). There were no season, season-treatment, year, and year-treatment effects ($P = 0.114$); however, a 3-way interaction occurred ($P = 0.029$). No difference ($P > 0.05$) was detected between comparison and experimental areas during spring 1990; however, scent station indices markedly decreased ($P < 0.05$) and remained lower on experimental areas after that time. Scent station indices immediately before aerial shooting of coyotes on experimental areas were greater ($P = 0.018$) than coyote responses to scent stations immediately after aerial shooting (Table 1). Coyote responses to scent stations declined 81.8% immediately following aerial shooting of coyotes on experimental areas (Table 1). From linear regression, coyote density on the experimental and comparison areas prior to removal efforts was estimated to be 0.12 ± 0.01 coyotes km^{-2}. Coyote density remained stable on the comparison areas throughout this study, whereas coyote density decreased to and remained at 0.06 ± 0.01 coyotes km^{-2} on the experimental areas after 9 months of seasonal coyote removal. Eighty one and 178 coyotes were collected for necropsy from the comparison and experimental areas, respectively.

Table 1. Coyote scent station relative abundance between the comparison and experimental areas and the percent reduction in coyote scent station activity (Percent of operable scent stations visited x 1000) before and after aerial shooting of coyotes on the experimental areas.

	Comparison Areas	Experimental Areas		
Season	Index	Pre-shooting Index	Post-shooting Index	Reduction (%)
Spring 90	180	158	7	95.6
Summer 90	205	34	14	58.8
Fall 90	170	92	8	91.3
Winter 90	200	124	36	71.0
Spring 91	200	116	10	91.4
Summer 91	178	100	10	90.0
Fall 91	188	77	15	80.5
Winter 91	188	92	22	76.1
Mean	189	99	15	81.8

Mean palatal ratio of juvenile and adult coyotes was 2.9 and 3.1, respectively. The number of adults on experimental areas in 1990 exceeded the number of juveniles ($X^2 = 11.01$, degrees of freedom = 1, $P < 0.05$). The juvenile:adult ratio on comparison areas was even in 1990 ($X^2 = 0.025$, degrees of freedom = 1, $P > 0.05$). During 1991, the juvenile:adult ratio did not deviate from a 1:1 relationship on either comparison or experimental areas ($X^2 < 3.51$, degrees of freedom = 1, $P > 0.05$). The number of males and females on comparison and experimental areas did not deviate from a 1:1 sex ratio ($X^2 < 2.02$, degrees of freedom = 1, $P > 0.05$) during 1990 and 1991 (Figure 1).

Juvenile coyote shoulder height increased ($P < 0.016$) while relative amount of back fat decreased ($P = 0.047$) during 1991 over 1990 estimates (Table 2). There were no differences ($P = 0.194$) in juvenile coyote mean body weight, length, shoulder height, age, and all relative fat indices between comparison and experimental areas (Table 2). Year-treatment interactions within the measured parameters were not detected ($P = 0.158$) for juvenile coyotes.

Adult coyote length and shoulder height increased ($P = 0.020$) during 1991 over 1990 estimates (Table 2). Relative amount of back, hip, and rib fat on comparison areas decreased ($P = 0.050$) during 1991 over 1990 estimates; however, relative amount of back, hip, and rib fat remained unchanged between the years on experimental areas (Table 2). There were no differences ($P = 0.085$) in adult coyote mean body weight, length, shoulder height, age, and relative amount of mesentery fat between comparison and experimental areas.

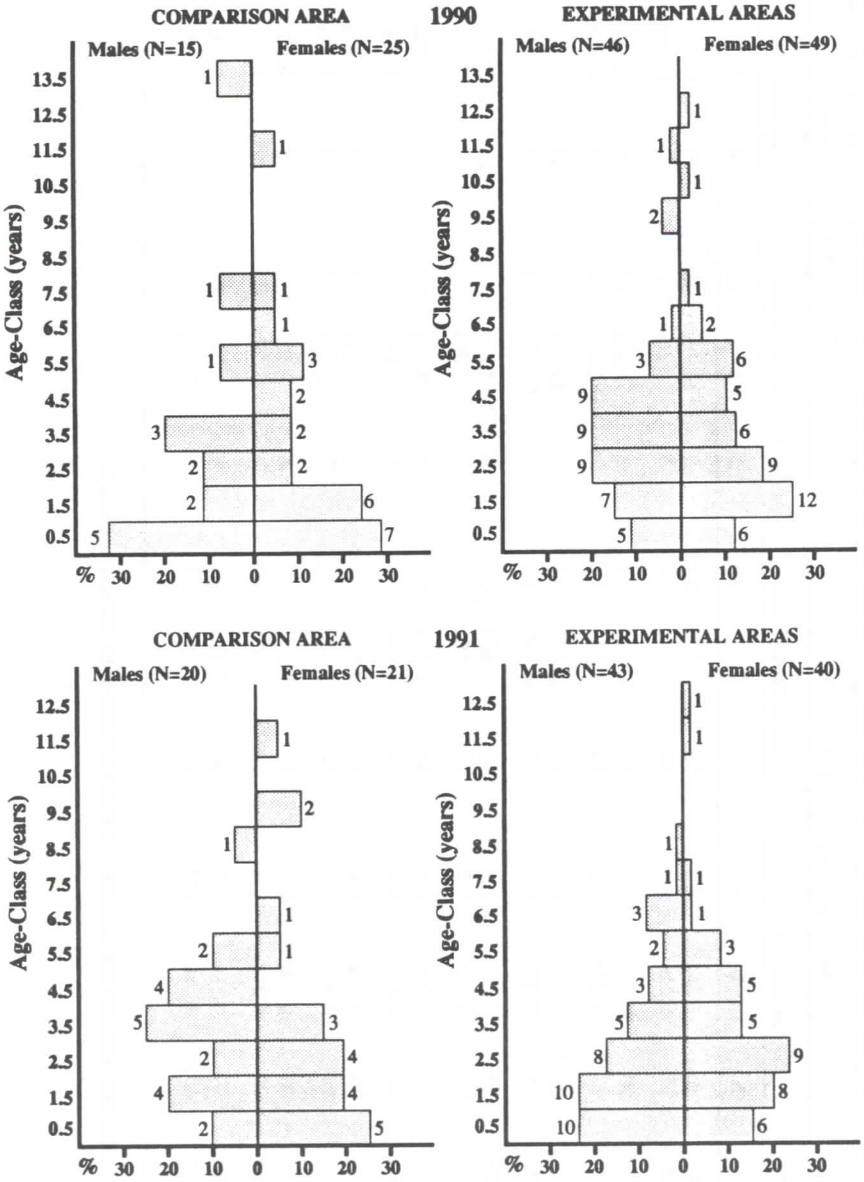

Figure 1. Population profile of coyotes on comparison and experimental areas during 1990 and 1991 in Andrews County, Texas.

Table 2. Age-specific mean body weight, length, height, age, and fat indices of coyotes from comparison and experimental areas, Andrews County, Texas.

		Juvenile Coyotes (< 1.0 years old)						Adult Coyotes (≥ 1.0 years old)					
		Comparison Areas			Experimental Areas			Comparison Areas			Experimental Areas		
Indices		N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE
Weight (kg)	1990:	20	8.84a[†]	0.2	30	8.58a	0.9	20	10.79a	0.6	65	11.18a	0.2
	1991:	15	9.51a	0.3	34	9.64a	0.4	26	11.21a	0.1	49	11.48a	0.2
Length (cm)	1990:	20	75.51a	1.5	30	77.90a	0.5	20	78.94a	0.2	65	80.98a	0.2
	1991:	15	77.37a	1.3	34	76.81a	1.5	26	82.42b	0.5	49	81.84b	0.5
Height (cm)	1990:	20	44.86a	0.2	30	45.57a	0.5	20	47.29a	0.5	65	48.97a	0.5
	1991:	15	49.22b	0.5	34	48.00b	1.5	26	51.13b	0.5	49	50.67b	0.2
Age (years)	1990:	20	0.45a	0.1	30	0.65a	0.1	20	4.75a	0.4	65	3.90a	0.4
	1991:	15	0.50a	0.2	34	0.50a	0.1	26	4.30a	0.6	49	3.90a	0.1
Back fat	1990:	20	1.00a	0.1	30	0.85a	0.2	20	1.20a	0.0	65	1.00a	0.1
	1991:	15	0.55b	0.1	34	0.60b	0.2	26	0.20b	0.1	49	0.75a	0.0
Hip fat	1990:	20	0.90a	0.0	30	0.80a	0.1	20	1.20a	0.0	65	0.85a	0.0
	1991:	15	0.30a	0.2	34	0.55a	0.2	26	0.20b	0.1	49	0.55a	0.0
Rib fat	1990:	20	0.90a	0.0	30	0.55a	0.2	20	1.10a	0.1	65	0.80a	0.1
	1991:	15	0.95a	0.2	34	0.65a	0.2	26	0.20b	0.2	49	0.60a	0.0
Mesentery fat	1990:	20	1.30a	0.1	30	1.30a	0.1	20	1.70a	0.0	65	1.45a	0.2
	1991:	15	1.15a	0.2	34	1.15a	0.1	26	1.20a	0.1	49	1.40a	0.2

†Means with the same lower case letter are not different ($P>0.05$) between years within a treatment.

Table 3. Comparison of juvenile and adult female reproductive parameters from comparison and experimental areas in Andrews County, Texas, during 1990 and 1991.

	Juvenile Coyotes (< 1.0 years old)						Adult Coyotes (≥ 1.0 years old)					
	Comparison Areas			Experimental Areas			Comparison Areas			Experimental Areas		
Indices	N	x̄	SE	N	x̄	SE	N	x̄	SE	N	x̄	SE
Primary scars												
1990:	3	0.67Aa†	0.7	2	0.00Aa	0.0	20	1.10Aa	0.2	43	1.70Aa	0.8
1991:	3	0.00Aa	0.0	3	1.00Aa	0.6	16	2.65Aa	0.4	33	2.05Aa	0.4
Resorption scars												
1990:	3	0.00Aa	0.0	2	0.00Aa	0.0	20	0.20Aa	0.1	43	0.15Aa	0.1
1991:	3	0.00Aa	0.0	3	5.67Bb	0.7	16	0.45Aa	0.2	33	0.45Aa	0.2
Corpora lutea												
1990:	3	1.33Aa	1.3	2	1.00Aa	1.0	16	2.80Aa	0.6	37	3.25Aa	0.8
1991:	3	0.67Aa	0.7	3	7.33Bb	0.9	12	3.95Aa	0.6	24	4.15Aa	0.1
Females breeding (%)												
1990:	3	0.33Aa	0.3	2	0.00Aa	0.0	20	0.70Aa	0.0	43	0.76Aa	0.2
1991:	3	0.00Aa	0.0	3	1.00Bb	0.0	16	0.80Aa	0.1	33	0.85Aa	0.1
Age (years)												
1990:	-	-	-	-	-	-	20	3.25Aa	0.4	43	3.15Aa	0.8
1991:	-	-	-	-	-	-	16	4.35Aa	1.0	33	3.35Aa	0.1

†Means with the same upper case letter are not different ($P > 0.05$) between treatments; means with the same lower case letter are not different ($P > 0.05$) between years within a treatment.

Adult female reproductive parameters were not different ($P = 0.546$) between comparison and experimental areas during 1990 and 1991 (Table 3). There were no year effects ($P = 0.066$) or year-treatment interactions ($P = 0.145$) detected in adult female reproductive parameters. The percent of females ovulating (ovaries containing follicles or corpora lutea) and the percent of females breeding (uterine horns containing implanted fetuses or placental scars) was the same ($P > 0.523$) between and within the treatment areas.

Juvenile female reproductive parameters were similar ($P = 0.495$) between comparison and experimental areas during 1990, and there was no difference ($P = 0.158$) in the number of primary placental scars between comparison and experimental areas during 1991 (Table 3). However, during 1991 the number of resorption placental scars and corpora lutea and the percentage of juvenile females breeding on the experimental areas was greater ($P = 0.004$) than on the comparison areas (Table 3). Also, the number of resorption scars and corpora lutea, and percentage of juvenile females breeding during 1991 increased ($P = 0.019$) on experimental areas from 1990. Juvenile female reproductive parameters did not vary ($P = 0.374$) among years on the comparison areas nor in the number of primary placental scars on the experimental areas. Six juvenile females were obtained during the January collections (approximately 9-month-old females). Juvenile females on the comparison areas (N = 2) did not appear sexually developed; however, all juvenile females on the experimental areas (N = 4) were pregnant and had an average of 6 ovulation sites and 6 implanted fetuses.

Totals of 18 and 26 fetuses were removed from female coyotes obtained during the January collection from the comparison and experimental areas, respectively. Of the sample obtained from the comparison areas, 14 fetuses were male and 4 were female, while fetuses obtained from the experimental areas contained 11 males and 15 females. Fetal sex ratios deviated from a 1:1 ratio ($X^2 = 4.5$, degrees of freedom = 1, $P < 0.05$) on the comparison areas but did not deviate from a 1:1 sex ratio ($X^2 = 0.35$, degrees of freedom = 1, $P > 0.05$) on the experimental areas.

DISCUSSION

Aerial shooting from a helicopter appeared to produce an immediate 80% reduction in coyote population size on the experimental areas. However, due to possible immigration (Gier, 1968; Knowlton, 1972), long-term effects of population reduction of coyotes were less dramatic, producing only a 48% decline.

The calculated palatal ratios were at the lower limit suggested for coyotes (Howard 1949). If the ratio is greater than 3.1, the specimen is a coyote; if the ratio is less than 2.7, it is a dog (*Canis familiaris*). However, range of palatal ratios depend on subspecies (Bekoff 1977). Selected skulls from coyotes collected in Andrews County were of the subspecies *Canis latrans texensis* as determined by Choate et al. (1992). Therefore, hybridization between coyotes and feral dogs was not observed.

Adult coyote back, hip and rib fat indices were lower on comparison areas during 1991 than the 1990 estimates. This could be a result of a less abundant food supply. Henke (1992) observed lower densities of jackrabbits and rodents and a greater percent of empty coyote stomachs on comparison areas during this time period. Decreases of back, hip, and rib fat deposits without loss of body weight suggests that back, hip, and rib fat deposits are more sensitive indicators of body condition than body weight alone. Windberg et al. (1991) found a similar relationship in coyotes from South Texas. A progressive sequence of fat deposition has not been determined for carnivores; however, the sequence is assumed similar to ungulates (Riney, 1955). Based on data from this study, the progressive sequence of measured subcutaneous fat deposition in coyotes from western Texas appears to be (1) back, (2) hip, and (3) rib fat.

The percentage of adult female coyotes that breed varies from 33% to 90% (Gier, 1968; Knowlton, 1972). However, in years with adequate food supply, a greater percentage of females will breed (Gier, 1968). Because coyote density decreased on experimental areas, and subsequently rodent and jackrabbit densities increased (Henke, 1992), we predicted coyote litter size and percentage of females breeding would increase. However, this was observed only in juvenile females. Perhaps one year was not sufficient time for adult female reproduction to respond to environmental changes. All of the juvenile females on the experimental areas bred before their first year and they expressed a greater fecundity rate after approximately 9 months of coyote removal. However, because juvenile females on the experimental areas experienced a greater resorption rate, their potential live-birth litter size was small, and therefore, they did not significantly contribute to coyote density. This agrees with Knowlton (1972) who stated that yearling females minimally contribute to coyote populations. The high resorption rate of juvenile females could have been caused by inadequate nutrition, high parasite loads, insufficient hormonal levels, or a combination of these factors. Our data provides evidence that the nutritional plane of juvenile coyotes may have been deficient. Although not statistically significant, declining fat reserves during 1991 may have been biologically significant.

Connolly and Longhurst (1975) suggest an inverse relationship between coyote density and coyote reproduction; however, they did not include age-specific differences in coyote reproductive rates within their simulation model. This could mean that coyote control programs may not always result in increased live-birth rates. Therefore, a minimum annual removal of 75% may not be required to lower coyote density.

Conception dates, based on average fetal growth (Kennelly et al., 1977), occurred during mid-January for coyotes on the comparison and experimental areas during 1990 and 1991. Assuming an average gestation of 63 days (Kennelly et al., 1977), coyote pups for western Texas were born during mid-to-late March. This is slightly earlier than was previously reported for western coyotes (Gier, 1968; Kennelly, 1978).

Sex ratio at birth of females to males is considered to be 1:1 (Bekoff, 1977). However, our data suggests that higher coyote densities may favor a greater number of male births. To our knowledge, this phenomenon has only been documented in wild cervids (Verme, 1969).

Although the small sample size of the reproductive data prevents drawing many statistically valid conclusions, the data nonetheless stimulate new questions concerning coyote population ecology. Additional research is needed to validate these new findings. Successful attempts to model and understand coyote population dynamics will require much larger samples of adult and juvenile females, and must include data on coyote density, sex ratio, and age structure.

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An Estimated Economic Value for the Audubon Sabal Palm Sanctuary

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ABSTRACT

The Audubon Sabal Palm Sanctuary near Brownsville, Texas, is recognized by bird watchers as a site to observe a large number of uncommon birds. The uniqueness of the birds and vegetation, mild winters, and easy access to an international airport and modern resort facilities attract bird watchers from all over the world. A technique to value recreation sites is the aggregate travel cost method. The method estimates economic value based on what visitors pay to travel to the site. Preliminary data on the total number of visitors, their origins, and party size were obtained from guest book registry at the sanctuary for 1990. Additional visitor characteristics were collected from a questionnaire administered to visitors in 1991. Results show visitors spend an average of $443.10 to travel to the sanctuary. On the basis of total visitors, the sanctuary generates $1.28 million per year. These results were compared to other recreational activities to contrast the value generated by bird watching. The estimated value and the number of visitors at other bird-watching sites in the region (such as Laguna Atascosa National Wildlife Refuge) suggest the need for additional studies to document more completely the value of non-game wildlife in the region.

KEYWORDS: bird watching, travel cost method

The 197-acre Audubon Sabal Palm Sanctuary adjacent to the Rio Grande near Brownsville, Texas, preserves a remnant plant community dominated by sabal palm (*Sabal texana*) trees that reach heights of 35-40 ft. The semi-tropical vegetation provides habitat for a number of rare vertebrates including the lesser yellow bat (*Lasirus ega*), hooded oriole (*Icterus cucullatus*), and northern cat-eyed snake (*Leptodeira septentrionalis*) (Jahrsdoerfer and Leslie, 1988). Consistent sightings of the buff-bellied hummingbird (*Amazilla yucatanensis*) and occasional sightings of the gray-crowned yellow-throat warbler (*Geothypis poliocephala*) on the sanctuary attract bird watchers seeking to add these species to their list of sighted birds (Farmer, 1991). Complimenting these species, which act as star attractions, are well documented descriptions of a wide variety of additional birds endemic to the Lower Rio Grande Valley.

The abundant information available serves to inform or alert bird watchers about the number and kinds of birds at the sanctuary. Just as the seriousness that bird watchers bring to their sport is wide, so is the documentation about the sport. Technical descriptions of the sanctuary for serious bird watchers exist in Oberholser

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(1974) and in Holt (1992). A telephone network maintained by the American Bird Association alerts bird watchers throughout the U.S. and internationally of rare bird sightings at the sanctuary (Pencelli, 1991). Articles such as Hodge (1992) publicize the sanctuary to the serious and casual nature enthusiast alike. Together, these documents have made the sanctuary a regular stop on the travel itinerary of serious bird watchers and a site that the more casual will learn about quickly.

Because visitors to the sanctuary accrue travel costs and give up other options, such as continuing to work and earning money when they make a choice to visit the sanctuary, an economic value can be estimated for the sanctuary. Goods or services that have economic value, but that are not directly valued through market exchange, are called non-market goods and services. Examples include clean air and water and recreation related to non-game wildlife, in particular, bird watching. Because the value of bird watching is not established through a market exchange, its economic value is not directly observable. In order to determine how much economic value the sanctuary generates, I estimated the average cost associated with a visit to the sanctuary using the travel cost method. Associated with estimating the trip cost, it was necessary to collect demographic data on site visitors. Because no descriptions of site visitors exist in the literature, this data was analyzed to give a brief description of the characteristics of site visitors. Several findings indicate most site visitors do not fit the stereotypical image of someone over-wintering in south Texas to escape a cold northern climate. The description should be useful to economists interested in describing the value of bird watching throughout the region rather than one site.

METHODS AND DATA

Economists have developed procedures for determining the economic value for different types of non-market items (Just et al., 1982; Crandall, 1992). One such procedure for valuing recreation sites is based on how much people spend to travel to an area. The method used in this analysis follows Rosenthal et al. (1984) and depends in part on the number of visitors and their origins. To derive an estimate of the value of the sanctuary, the travel cost method was applied to 1990 guest-book registration data. Guest registry that year (Farmer, 1991) showed 1,979 visitors (Figure 1).

When applying the aggregate travel cost method in this study, I assumed all visitors have similar demand preferences. Visitors must also originate from diverse locations. When a visitor has to travel farther to reach the site, their costs increase, and the quantity of visitors from distant sites decreases. This inverse relation between the cost and the number of visitors forms the basis for the estimation of a demand curve, which is used to establish the value generated by the sanctuary. The demand curve more generally represents the number of visitors to the site given any particular travel cost. Moreover, the area underneath the demand curve represents the sum of all visitors' willingness to pay to visit the site or the value of the resource.

Origins of travel were established using the following rules. All visitors from within Texas were assigned to the county of origin, and travel costs were based on the mileage from the county seat to the sanctuary. Visitors from outside Texas but in the U.S. were assigned the state of origin, and travel costs were based on the mileage from the respective state capital to the sanctuary. Visitors outside the U.S. were assigned to the country of origin, and mileage was based on the distance from the capital of the country to the sanctuary.

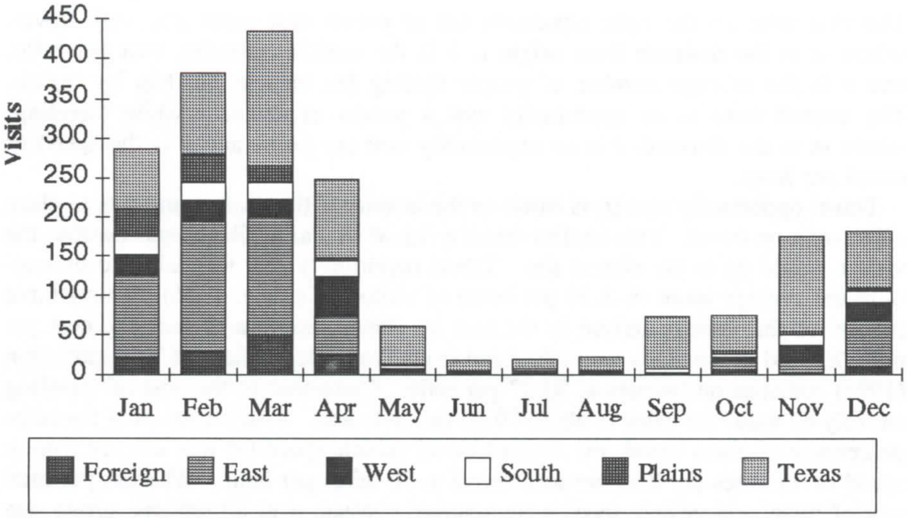

Figure 1. Visits registered in the 1990 guest book at the Audubon Sabal Palm Sanctuary near Brownsville, Texas, by geographic origin of visitor and month of visit.

Besides the actual cost of travel having an effect on the quantity of visitors arriving at the site from any particular origin, Rosenthal et al. (1984) lists several other variables that affect the number of visits. These include:

$$q_i = f(c_i, n_i, s_i, a, d_i)$$

where q_i is the quantity of visits from the i-th origin, c_i is the travel cost from the i-th origin, n_i is the population of the i-th origin, s_i is a measure of the substitutes for the site from the i-th origin, a is a measure of the site characteristics, and d_i is a measure of demographic characteristics for origin i such as income and education. In the estimation, population bias (total visits being larger from a higher populated region even though the two regions are the same distance from the site) was controlled by expressing total visits from any region as regional per capita visits or $r_i = q_i/n_i$.

Because the site represents an opportunity to observe several birds in a plant habitat that does not exist elsewhere in the U.S., the substitute term, s_i, was omitted.

Similarly, rather than try to establish a measure of overall sanctuary characteristics, the final demand estimate was thought to capture the effect of site characteristics on trip visits. A per person dollar cost of a round trip from the i-th origin was estimated based on the following relation:

$$c_i = (m_i * k)/e_i + (m_i * t)/v$$

The first term on the right represents out of pocket cost associated with travel, where m is the distance from origin i, k is the vehicle operating cost per mile, and e is the average number of people sharing the vehicle per trip by region. The second term is an opportunity cost a person experiences while traveling, where m is the distance, t is an opportunity cost per hour, and v is the speed of travel per hour.

Travel opportunity cost (t) is based on the income of the visitors and acts to place a deterrent on travel. This implies that if a site of similar attributes was nearby, the visitor would go to the closest site. Travel opportunity cost was taken to be one-third the average wage ($18.30 per hour) of visitors (Cesario, 1976). Thirty-three percent of the visitors arrived in the area by plane. Because of this, the cost per mile (k) used in the study was calculated from Texas Department of Transportation (1991) statistics on tourists at $0.17 per mile. Compared to the cost of traveling entirely by auto, the value is about $0.10 per mile less. Also recognizing the large percentage of plane travel, the average travel vehicle speed (v) was inflated from a speed of 45 miles per hour for auto travel to 70 miles per hour. Whereas per mile cost of travel and vehicle speed were assumed constant over all regions, group size was calculated for each region based on guest registration data. Averaged across all origins, however, the average party size was 2.9 people.

The number of destinations or sites to visit per trip can also affect final results. If there are no side trips, then costs accrued by the visitor are all attributed to the value of the recreation site, otherwise a method for allocating costs among the various trip destinations needs specification. The method used by Haspell and Johnson (1982) was used to divide total trip cost by number of destinations. An average of 4 sites (all within a four county area) were visited while on the trip. Final model estimation and evaluation utilized linear regression analysis and numeric integration routines provided in RMTCM (Rosenthal et al., 1986).

Travel opportunity cost, cost per mile, vehicle speed, and average regional party size were determined based on summary information obtained by analyzing a questionnaire completed by 96 people in 1991. Additional analysis was made of the questionnaire data to explore percent frequencies and correlations between key visitor behaviors and their demographic characteristics. The correlations were calculated with commercial software (First Mark Technologies, 1990; Biggs et al., 1991). Reported correlations are significant at a 0.05 level.

RESULTS AND DISCUSSION

Frequency analysis of the questionnaire showed about 70% of the visitors were on their first visit, 20% had been once before, and the remainder had been twice or more. Seventy-four percent stated bird watching as their reason for visiting, and 64% belonged to a nature organization. Thirty-two percent of the visitors learned of the sanctuary through travel guides, 22% through other refuge staff, and 19% through books. Considering visitor age, race, and income: 2% were less than 21 years old, 27% were between 21-40 years of age, 38% were between 41-55 years of age, and 33% were older than 55 years of age. Ninety percent listed themselves as Caucasian with the remaining 10% split evenly between Hispanic and an other category. Twenty-seven percent reported earning less than $20 thousand, 31% earned between $20-40 thousand, 24% between $40-60, and 18% earned more than $60 thousand.

Regarding travel arrangements, 57% made the decision to visit the site within the week prior to the excursion. Twenty-two percent had planned from a week to a month prior to their visit, and 21% had made travel arrangements 6 months prior to the trip. Thirty-three percent rented cars (the same as those traveling by air) and 45% of the visitors stayed in hotels. Fifty-six percent stayed in the region less than a week. In addition to the sanctuary, the most popular sites to visit while on the trip were the Santa Ana Refuge with 20% of the total side trips, 17% to the Laguna Atascosa Wildlife Refuge, 16% to Bentsen State Park, and 11% to South Padre Island.

Examining correlations between visitor characteristics, those earning higher incomes were most likely to belong to a nature organization. Repeat visitors were most likely to have traveled by plane; in fact, 30% of plane travelers had visited before. Travel size was most closely correlated to region of origin, and England produced the largest parties and most foreign visitors. Visitors indicating a return visit in the future indicated educational or bird watching as the reason. Those indicating bird watching as their reason for visiting were more likely to arrive in the area by plane or bus. Bird watchers and educational groups were most likely to have planned the current trip in advance. Hikers and the curious were the most spontaneous arrivals. Interestingly, those who had been to Bentsen State Park were most likely to have learned of the sanctuary through a book. There tended to be a high correlation between side trip visit sites. For example, those visiting Santa Ana Refuge tended to visit Laguna Atascosa refuge and Bentsen State Park.

The variable most closely linked to race was region of origin. All Mexican visitors indicated Hispanic. Within the U.S., the distinction between Hispanic and Caucasian was linked to the visitor's state of origin. Texas produced the most Hispanic visitors, and young visitors were most likely to be Hispanic. The mode of travel, private car versus rental car, was not unexpectedly linked to those who arrived by plane. Plane travelers were those most likely to rent cars. The length of stay was most closely linked to lodging the previous night. Visitors who stayed in hotels commonly stayed between 1-3 weeks. Travelers staying longer were most likely to have stayed in a recreational park and traveled by recreation vehicle. Out-of-state visitors tended to be more affluent, older, and on a trip averaging less than a week. This description suggests most visitors to the site are visiting for the intended purpose of bird watching. That a group of individuals is planning to visit the Valley area specifically for bird watching is important for regional policy planning.

Turning to the estimation of the travel cost model, several functional forms were estimated. A double log model with the natural log of per capita visits, r, a function of the natural log of the transformed costs, c, gave the best statistical results. Estimated coefficients and t-values (underneath) are:

$$\ln(r) = -4.85 - 1.11 * \ln(c)$$
$$(6.99) \quad (9.29)$$

The overall fitness of the equation as indicated by the F value was 84.81, with 90 degrees of freedom. The estimated average cost per person per trip is \$443.10. The value can be converted to \$6,497 per acre per year of value generated by the sanctuary or \$1.28 million for the entire sanctuary. Moreover, the sanctuary is like any other productive asset that generates benefits not just this year, but next year, the year after, and so on. Assuming present benefits hold constant over the next 50 years and at a 7% interest rate, a net present value of \$17.6 million for the sanctuary is generated by visitors.

Frequently, studies report the value of trips as per person per day. At the sanctuary the visitor's length of stay is skewed toward short visits, 76% stayed on their trip for less than a week. This result makes the value of the trip close to the value of the per person per day expense for most visitors. Yet, a few visitors did stay for longer periods (over the winter). Adding these longer staying visitors into the equation creates a higher average length of stay (26.12 days), which yields a per person per day value of \$67.86.

Given the caveat that most visitors stay less than the average length of stay (implying a higher per person per day value than \$67.86), it is useful to compare the results to estimates obtained for hunting recreation. For example, deer hunting values have ranged between \$26.79 to \$114.61 per person per user day (Donnelly and Nelson 1986). Sorg and Nelson (1987) calculated a value of \$28.51 for waterfowl hunting in Idaho. McCollum et al. (1990) estimated a per trip value of \$170.79 for wildlife observation in Alaskan national forests and had a large percentage of visitors who traveled long distances. But, because the visitors stayed long periods, when converted to per person per day values, the values are relatively low at \$6.53.

When compared to other wildlife based recreation studies, the low range value of \$67.86 per person per day at the sanctuary is within the values obtained for other studies. Although the per person per trip value of \$443.10 is out of the range of the other studies, if it is assumed to be a more accurate measure of the per person per day cost of visiting the sanctuary, several characteristics of the sanctuary support a value that would be higher than the other studies. In particular, the large percentage of long distance travelers and limited, if any, sites where the birds at the sanctuary can be seen in a similar environment.

While the estimated value is thought to be an accurate estimate of the true value of the sanctuary, refinements in input data could be made such as assigning each region its own average travel cost and vehicle speed. Another aspect that should receive attention in future studies is the allocation of costs to side trips. Mendelson et al. (1992) review the problem and provide an application of an alternative model. The present study was meant to provide an initial measure for gauging the need for more in depth investigations. The relatively high estimated per trip value of \$443.10 needs additional corroboration.

Economic factors also suggest additional research. Although the total value generated by the sanctuary is not a value which contributes directly to the local economy (compared to tourist expenditures), it does contribute to overall economic value. Also, travel plans made by visitors at the sanctuary indicated the importance of three other locations within close proximity; Laguna Atascosa National Wildlife

Refuge, Santa Ana National Wildlife Refuge, and Bentsen State Park. A total of 793,371 visits were made to these areas in 1990. Extrapolating similar per trip values estimated from the sanctuary to these visits would yield a large economic value. Additional research should address the accuracy of such an extrapolation. Also, the Texas Department of Commerce (1991) ranked Cameron County, which contains the sanctuary, Laguna Atascosa Refuge, and the resort at South Padre Island, as tenth in capturing tourist expenditures in Texas. Another area research should focus on is the role bird watching plays in generating tourism dollars in the Valley area. If bird watchers to all the sites in the region share demographic characteristics as those visiting the site, then they may be adding a significant value to the local economy through tourist expenditures such as car rental, hotels and restaurants.

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Insecticidal Management of Thrips in Texas Peanut Fields

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ABSTRACT

Studies testing insecticidal compounds against thrips feeding in peanut were conducted at two sites in Texas--Stephenville (Erath County) in the northern region and Pearsall (Frio County) in the southern region. Products tested were aldicarb, acephate and disulfoton in at-plant, sidedress and split applications, and sulfur in split applications. Thrips populations were sampled weekly in terminals and flowers. A weekly census of both the number of terminals and flowers was used to establish absolute population densities of thrips. Control was obtained with all compounds tested except sulfur. However, control in northern Texas was reduced compared to studies conducted in previous years.

KEYWORDS: Thysanoptera, *Frankliniella fusca*, *Frankliniella occidentalis*, *Arachis hypogaea*

Thrips are not usually considered to be a major pest of peanut (*Arachis hypogaea* L.) (Smith, 1981). Feeding damage by adults and larvae causes unsightly leaf scarring, especially in small plants, but yields are not normally increased by insecticidal control (Smith and Sams, 1977). However, thrips become a severe pest of peanut when they vector tomato spotted wilt virus (TSWV) (Mitchell et al., 1990). The two most common species of thrips feeding in peanut are the tobacco thrips [*Frankliniella fusca* (Hinds)] and the western flower thrips [*Frankliniella occidentalis* (Pergande)] (Mitchell and Smith, 1991), both of which are capable of transmitting TSWV (Sakimura 1962, 1963).

TSWV epidemics may spread through peanut fields in two ways. Primary spread is propagated by immigrant thrips bringing the disease into the field from sources outside the field. Insecticidal control will probably not result in economic benefit in this circumstance, as the incoming thrips will likely feed and transmit the disease before being killed (Chamberlin et al. 1992). Secondary spread occurs when thrips acquire TSWV from diseased peanut plants in the field and trasmit it to other uninfected plants in the same field. Since only immature thrips can acquire TSWV for later transmission (Bald and Samuel, 1931), insecticidal control might provide relief (Mitchell et al., 1990). Earlier reports on control of thrips in Texas peanut indicated that up to 100% kill could be obtained (Smith and Sams, 1977; Sams and Smith, 1978; Smith et al. 1982). However, observations by the authors in grower fields in 1987 indicated control was erratic. The objective of this study was to

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determine efficacy and duration of thrips control for variously timed foliar and granular applications of labelled insecticides. In addition, sulfur was included to determine whether or not it would act as a feeding deterrent at a reasonable application rate.

MATERIALS AND METHODS

Two tests were conducted. The first was on the grounds of the Texas Agricultural Experiment Station in Stephenville. Four replications of each treatment were made in a randomized complete block design. Each treatment plot was 4 rows (36 in [0.91 m] centers) by 30 feet (9.14 m) long. Six feet (1.83 m) of buffer space was left between plots in a block and ten rows between blocks. These treatments are listed in Table 1.

The treatments were made on Florunner peanut that was planted 26 May 1988, and emerged one week later. Treatments 1, 3, 4,and 6 were made on 27 May. Treatments 7, 8, 9, 10, and 11 were made on 17 June. Treatments 2 and 5, and split treatments 3, 6, and 8-11 were made on 7 July. All plots were irrigated as necessary. The field was given standard treatments of herbicide and fungicide. Sampling began with the appearance of the first terminals and continued for ten weeks. A sample consisted of five terminals, and each sample was placed in a bottle with a preservative and surfactant (AGA; Mound and Pitkin, 1972). The bottle was shaken and the plant parts discarded. The solution was filtered and the number of adult and immature thrips counted. This number was adjusted to account for the thrips discarded in the foliage and flowers (data not shown). Five samples were drawn weekly from each plot in each block. At the onset of flowering, five samples of five flowers each were also collected. Since terminals and flowers represent the major niches for thrips feeding in peanut, an absolute population density was obtained.

The second test was conducted in an irrigated production field in Frio County. The purpose of this experiment was to determine if sidedress or split treatments were effective as used. All plots received the same herbicide and fungicide treatments as the rest of the field. The field was planted in Florunner peanuts on 7 June 1988. Peanuts emerged 7-10 days later and were treated at-plant with aldicarb 15G in-furrow at 1 lb ai acre^{-1} (1.12 kg ai ha^{-1}) by the grower. Four 0.155 acre (0.063 ha) areas were left untreated, one at each cardinal compass point. Each of these four areas was combined with an equal sized area of the production field to make four blocks 0.31 acres (0.125 ha) in size. Treatments within the study are found in Table 2.

Two replicates of each treatment were made in each block. Samples were collected and processed as in the first test for eight consecutive weeks.

A census was made weekly of the number of terminals and flowers per meter (39.4 in) of row in each plot. For terminals, these values were averaged over all treatments and multiplied by the number of thrips per terminal in each sample to obtain an estimate of the number of thrips per meter of row in the sample. Flower census samples were treated similarly in Pearsall data. In Stephenville census data, flower averages were made by block, and sample data from each block was multiplied by the appropriate value for that week. The number of thrips per meter of row in terminals was added to the same value for flowers to obtain a total number of adult or larval thrips per meter of row on which to perform analysis.

Table 1. Insecticide application methods and rates for Stephenville experiment on Florunner peanut planted 26 May 1988.

Treatment	Application Rate	Application Method	Application Timing
	lb acre^{-1} (kg ha^{-1})		
Aldicarb 15G	1.0 (1.12)	Banded	At plant[†]
Aldicarb 15G	1.5 (1.68)	Banded	At peg[‡]
Aldicarb 15G	1.0 (1.12) 1.5 (1.68)	Banded	Split, at plant & at peg[§]
Disulfoton 15G	1.3 (1.46)	Banded	At plant[†]
Disulfoton 15G	1.3 (1.46)	Banded	At peg[‡]
Disulfoton 15G	1.3 (1.46) 1.3 (1.46)	Banded	Split, at plant & at peg[§]
Acephate 75S	0.75 (0.84)	Foliar spray	One week after crack[¶]
Acephate 75S	0.75 (0.84) 0.75 (0.84)	Foliar spray	Split, one week after crack & at peg[#]
Sulfur 53EM	1.0 (1.12) 1.0 (1.12)	Foliar spray	Split, one week after crack & at peg[#]
Sulfur 53EM	2.0 (2.25) 2.0 (2.25)	Foliar spray	Split, one week after crack & at peg[#]
Sulfur 53EM	3.0 (3.37) 3.0 (3.37)	Foliar spray	Split, one week after crack & at peg[#]
Untreated check	-	-	-

†27 May
‡7 July
§27 May and 7 July
¶17 June
#17 June and 7 July

Data were analyzed with the General Linear Model option of SAS (Statistical Analysis Systems, Cary, NC). If the overall analysis was significant at a level of 95%, then the means of the treatments were separated with a Duncan's Multiple

Range test. Again, a 95% difference threshold between means was used to determine if treatments were different from the untreated check plots.

Table 2. Insecticide application methods and rates for Pearsall experiment on Florunner peanut planted 7 June 1988.

Treatment	Application Rate	Application Method	Application Timing
	lb acre^{-1} (kg ha^{-1})		
Aldicarb 15G	1.0 (1.12)	In furrow	At plant†
Aldicarb 15G	1.5 (1.68)	Banded	50 days post-plant‡
Aldicarb 15G	1.0 (1.12) 1.5 (1.68)	In furrow banded	At plant & 50 days post-plant§
Disulfoton 15G	1.4 (1.57)	Banded	50 days post-plant‡
Untreated check	-	-	-

†7 June
‡27 July
§7 June and 27 July

Adult thrips census data were regressed against flower census data to determine if flower density affected population density. The GLM option of SAS was used to conduct this analysis.

RESULTS

Because adult and larval thrips differ so much in mobility (most adults have wings while the larvae are flightless), the results are tabulated by these two stages. The results are also separated by location, Stephenville and Pearsall. Generally speaking, the analysis could not detect population differences smaller than about 30% between insecticide treatments. Only the first eight weeks are shown for Stephenville results (Tables 3 and 4), as no differences between treatments were detected after this. Eight weeks of the Pearsall test are also shown (Tables 5 and 6, beginning at 50 days post-planting), but no differences in treatments were found after the first 4 weeks of the test. Eight weeks of census data are shown in the figures. Week 1 (Figure 1) begins the first week of crack (when seedling first push through the soil) or 16 days post-planting, on 12 June before the treatment. Week 1 in Figure 2 begins 50 days after planting, before the treatment on 27 July.

Table 3. Mean number of thrips larvae per meter of row in the Stephenville experiment, including samples from both terminals and flowers. Week 1 of the experiment began 16 days after planting.

	Week							
Treatment	1	2	3	4	5	6	7	8
Disulfoton plant	14.9bc[†]	68.2abc	224.7bcd	324.8ab	413.2ab	404.4a	718.3bcd	256.8 bc
Disulfoton side	42.7a	81.6ab	350.9a	297.8abc	298.3bcd	311.1abc	1121.8a	294.1 bc
Disulfoton split	14.3bc	46.4cde	200.8cd	380.7a	407.2ab	281.6bcd	641.6cd	260.7 bc
Aldicarb plant	4.1c	13.9f	132.8de	223.2bcd	399.1ab	318.2ab	424.3de	111.3 d
Aldicarb side	10.8bc	83.3ab	284.9abc	345.8ab	341.1bcd	201.9cde	909.6abc	72.1 d
Aldicarb split	6.3bc	22.8fe	76.8e	163.6d	274.5cd	102.5e	245.2e	71.8 d
Acephate 1X	23.3abc	29.5def	50.2e	312.9ab	388.0abc	345.4ab	162.3e	280.5 bc
Acephate 2X	21.9abc	24.5def	47.0e	183.8cd	248.9d	184.3de	151.1e	124.0 d
Sulfur 1 lb	16.4bc	81.7ab	301.1ab	314.6ab	378.2abc	396.3ab	963.4ab	353.1 ab
Sulfur 2 lb	30.1ab	91.9a	324.5a	303.7abc	312.0bcd	425.4a	1036.7a	228.1 c
Sulfur 3 lb	15.1bc	55.7bcd	349.3a	394.2a	475.7a	402.6a	1115.3a	421.3 a
Untreated check	21.9abc	52.3bcde	300.6ab	296.1abc	355.6bcd	431.2a	960.5ab	344.4 ab

[†] In a column, numbers followed by the same letter are not significantly different at $P < 0.05$.

Table 4. Mean number of adult thrips per meter of row in the Stephenville experiment, including samples from both terminals and flowers. Week 1 of the experiment began 16 days after planting.

	Week							
Treatment	1	2	3	4	5	6	7	8
Disulfoton plant	26.5 abc[†]	32.2 b	78.7 a	105.5 abc	208.4 ab	160.1 a	253.5 a	225.4 ab
Disulfoton side	36.0 a	42.7 ab	71.8 a	84.9 bcd	202.5 ab	128.7 a	230.1 a	166.0 ab
Disulfoton split	22.0 cde	41.4 ab	95.1 a	86.9 bcd	244.5 a	138.6 a	304.4 a	206.4 ab
Aldicarb plant	16.9 de	21.4 c	82.9 a	89.6 abcd	245.2 a	107.3 a	265.1 a	158.2 b
Aldicarb side	31.9 ab	44.8 a	81.7 a	104.3 abc	189.1 ab	118.5 a	261.3 a	67.8 c
Aldicarb split	14.8 e	20.8 c	54.9 a	68.1 d	158.0 bc	120.6 a	176.1 a	70.2 c
Acephate 1X	28.2 abc	16.6 c	81.7 a	87.1 bcd	173.1 bc	160.1 a	262.0 a	238.5 a
Acephate 2X	25.3 bcd	12.4 c	73.5 a	79.5 cd	134.8 a	169.7 a	235.9 a	173.0 ab
Sulfur 1 lb	30.0 abc	40.1 ab	78.8 a	114.2 a	212.8 ab	118.8 a	252.8 a	173.8 ab
Sulfur 2 lb	34.4 ab	46.9 a	85.2 a	99.3 abc	210.6 ab	168.4 a	273.0 a	166.8 ab
Sulfur 3 lb	30.5 abc	49.0 a	78.2 a	106.3 ab	214.7 ab	172.4 a	251.1 a	224.1 ab
Untreated check	30.5 abc	41.9 ab	75.3 a	91.1 abcd	194.9 ab	139.2 a	241.5 a	180.8 ab

[†] In a column, numbers followed by the same letter are not significantly different at $P < 0.05$.

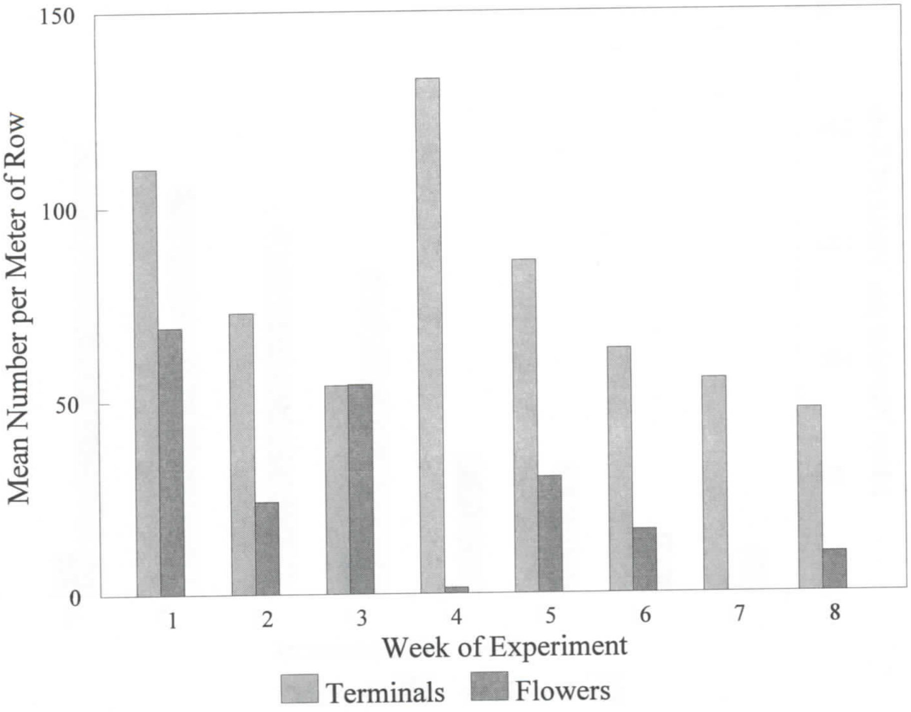

Figure 1. Weekly census of terminals and flowers in Stephenville peanut field plots. Week 1 of the census began 16 days after planting.

Table 3 presents control of larvae achieved at Stephenville. The best results were obtained in the aldicarb and acephate plots. Some measure of control resulted in the disulfoton split treatment plots, while sulphur gave significant results on only one date. Suppression of adults at Stephenville was much more difficult (Table 4). Aldicarb gave two weeks control after peanut emergence, and acephate provided control for one week. Aldicarb sidedress also caused significant population reductions. Control was more pronounced in Pearsall, but lasted only four weeks. Larvae were controlled by all treatments (Table 5). The aldicarb at-plant treatment continued to provide a degree of control against larvae through week 4 of the experiment. Adults were again more difficult to suppress (Table 6). All treatments except for aldicarb at-plant provided some degree of control against adults, as would be expected since the first sample was taken 50 days after planting.

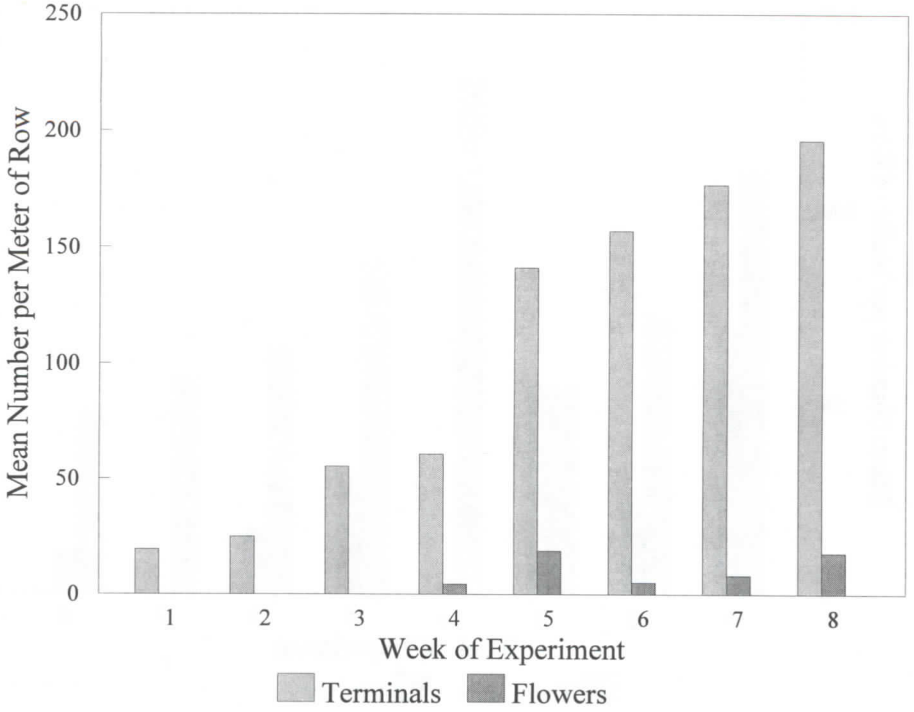

Figure 2. Weekly census of terminals and flowers in Pearsall peanut field plots. Week 1 of the census began 50 days after planting.

DISCUSSION

Insecticidal efficacy against thrips in Texas peanut has been reduced since tests were first conducted in the 1970s. Against larval thrips, Smith and Sams (1977) were able to achieve 100% and near 100% control of tobacco thrips in peanut foliage at the same location in Stephenville using aldicarb and disulfoton applied at-plant. Acephate, however, was used as a seed treatment by Smith and Sams (1977) and caused plant stand reduction. In the current study, it was applied as a foliar spray. Rohlfs et al. (1981) used acephate as a seed treatment but did not obtain control of thrips feeding in Alabama peanut plots. Phytotoxic effects of the seed treatment were not noted. Tappan and Gorbet (1979) successfully used acephate sprays for control of thrips in a variety of treatments, some of which provided greater than 90% control. Lynch et al. (1984) controlled thrips with aldicarb, while

Table 5. Mean number of thrips larvae per meter of row in the Pearsall experiment, including samples from both terminals and flowers. Week 1 of the experiment began 50 days after planting.

	Week							
Treatment	1	2	3	4	5	6	7	8
Disulfoton side	61.6 a[†]	5.0 c	20.7 bc	42.5 b	81.0 a	220.7 a	77.9 a	63.3 a
Aldicarb plant	15.4 c	39.5 b	31.4 b	70.8 b	36.2 b	213.1 a	48.1 a	48.6 ab
Aldicarb side	53.7 ab	7.8 c	11.5 bc	50.5 b	30.1 b	103.6 b	36.7 a	63.0 a
Aldicarb split	33.3 bc	7.8 c	4.9 c	53.4 b	36.1 b	81.5 b	42.4 a	52.3 ab
Untreated check	44.5 ab	112.7 a	63.3 a	177.3 a	49.0 b	151.1 ab	33.7 a	33.5 b

[†] In a column, numbers followed by the same letter are not significantly different at $P < 0.05$.

Table 6. Mean number of adult thrips per meter of row in the Pearsall experiment, including samples from both terminals and flowers. Week 1 of the experiment began 50 days after planting.

	Week							
Treatment	1	2	3	4	5	6	7	8
Disulfoton side	94.0 a†	18.7 b	36.8 a	22.3 b	49.2 a	12.2 b	5.9 a	6.9 b
Aldicarb plant	20.3 b	75.3 a	23.3 ab	70.4 a	22.8 bc	43.7 a	6.3 a	17.8 a
Aldicarb side	92.1 a	9.6 b	5.1 c	14.8 b	32.0 b	8.9 b	13.4 a	8.0 b
Aldicarb split	86.0 a	11.6 b	14.7 bc	8.3 b	26.5 bc	14.0 b	7.6 a	8.0 b
Untreated check	45.7 b	73.6 a	30.4 ab	70.8 a	14.2 c	22.3 b	9.3 a	12.8 ab

†In a column, numbers followed by the same letter are not significantly different at $P < 0.05$.

Tappan and Gorbet (1981) did the same with both aldicarb and disulfoton.

Adult thrips were not controlled as effectively as larvae in previous studies (Smith and Sams, 1977; Tappan and Gorbet, 1979, 1981; Lynch et al., 1984), a fact that is also reflected in the current research. As adults are more mobile, this is not surprising. This study also adds a dimension in that populations of terminals and flowers per unit area are also considered, providing for absolute density estimates of thrips populations when counts are made from the plant samples. Tappan (1986) investigated the effect of flowers on thrips populations, but in a fixed system where excess flowers were removed from experimental plants. Adult thrips often prefer flowers to terminals (Tappan, 1986), and as can be seen in Figure 1, flowers are an ephemeral habitat. There was no relationship between density of flowers and density of adult thrips by regression analysis in Pearsall ($F=0.06$, $P>0.05$), but there was in Stephenville ($F=9.34$, $P<0.05$). However, peak thrips populations in Stephenville were much higher than in Pearsall, which may have contributed to the reduced efficacy at the Stephenville site as compared to the Pearsall site. Historically, thrips populations at the Stephenville site have been high--as many as 47 per terminal have been reported (Sams and Smith, 1978).

Mitchell et al. (1990) reported decreases in TSWV infection in south Texas when insecticides were used against thrips. Prevalence of TSWV fell from 14% to 8%. This would imply that reductions in thrips populations resulted in a decrease in secondary spread of the virus. However, given the lack of complete control of thrips by insecticide, it is difficult to separate the impact of secondary infection from primary infection. Remedial treatments of insecticide for reduction of TSWV via thrips vector control are therefore of uncertain value in South Texas.

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Avian Responses During Winter to Sorghum Management in the Coastal Bend of Texas

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ABSTRACT

Post-harvest grain sorghum treatments were studied to determine those most used by birds during fall and winter 1990-92 in the Coastal Bend area of Texas. Treatment areas were allowed to grow a second seed head following harvest (July-December), then six treatments were applied in December. Bird species richness was higher in double-shredded ($\bar{x}$ = 11.5) and single-shredded ($\bar{x}$ = 10.8) than in harvested-only ($\bar{x}$ = 7.7), shred-disced ($\bar{x}$ = 8.8), shred-chisel plowed treatments ($\bar{x}$ = 6.0), or controls ($\bar{x}$ = 5.5) during post-treatment period (December-February). Post-treatment densities (birds ha^{-1}) of both ducks and geese were higher ($P < 0.10$) in double-shredded (ducks $\bar{x}$ = 39.1, geese $\bar{x}$ = 38.9) than in all other treatments (ducks $\bar{x}$ = 2.45, geese $\bar{x}$ = 3.58). Upland game bird (primarily dove and quail) densities were highest in shred-disced treatments ($\bar{x}$ = 6.04), while nongame bird (44 species) densities were highest in harvested-only ($\bar{x}$ = 18.4), double-shredded ($\bar{x}$ = 18.9), and shred-disced treatments ($\bar{x}$ = 20.69). Sorghum seeds remained available in treatments through February during the dry conditions in 1990-91. Sorghum availability declined to zero in all treatments prior to treatments in December 1991 (due to moisture-related decay), yet sorghum stubble remained an important habitat for wintering birds.

KEYWORDS: forage, nongame birds, upland game birds, waterfowl

Post-harvest cropland management affects food availability for many species of wildlife that depend on agricultural fields during winter. Cropland management strategies in the Coastal Bend of Texas have changed in recent years to promote earlier planting of crops (Refugio County farmers, pers. commun.) Fields are cultivated more intensively to prepare land for planting and are kept clean of waste grain or vegetation throughout fall and winter. Normal farming practices include repeated cultivation starting immediately after crops are harvested (July-early August) keeping fields void of all residue and vegetation throughout fall and winter if conditions allow access to fields.

Grain sorghum is the primary high-energy food grown in southern Texas. Birds such as geese rely on crop fields in this area to maintain adequate body condition

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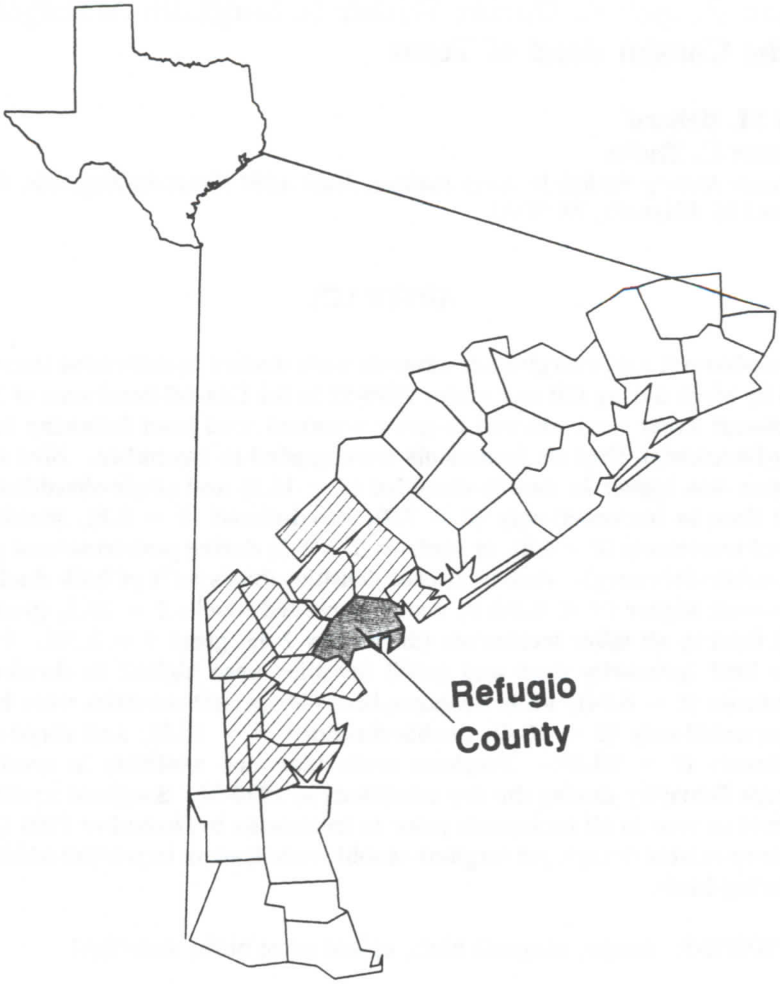

Figure 1. Location of Refugio County in the Coastal Bend (shaded area) of Texas.

throughout winter and provide adequate nutrient reserves for spring migration and nest initiation (Glazener, 1946; Reed, 1976; Ankney and MacInnes, 1978; Raveling, 1979; Bellrose, 1980). Goose use of the Coastal Bend has declined in recent years despite generally increasing populations (Tex. Parks and Wildl. Dep., unpubl. data). Clean farming may be causing this decline (C. R. Wilson, Soil Conserv. Serv., pers. commun.).

The objective of this study was to evaluate waste grain availability and avian abundance in fields under selected sorghum management practices in the Coastal Bend of Texas.

Research was conducted September 1990 to February 1991 and August 1991 to

February 1992 on sorghum set-aside fields on private lands in Refugio County, Texas (Fig. 1). The terrain is coastal prairie intermingled with streams and bays, with little variation in elevation except on the western boundary, where it is gently rolling (Guckian, 1984). Climate is subtropical with an average annual rainfall of 98.5 cm; maximum monthly precipitation typically occurs in September. Average seasonal temperatures range from 28°C in summer to 14°C in winter. The growing season averages 304 days, with the frost period generally occurring from 15 December to 14 February (Morrison, 1990). Common soil types are clayey and loamy. Approximately 78% of the land is used for livestock grazing, and 19% is in cropland. Grain sorghum and cotton are the major cash crops of the area (Guckian, 1984). Crop rotation of two years sorghum and one year cotton is typical. Sorghum harvesting generally concludes in early August.

METHODS

Study plots were comprised of grain sorghum fields in the set-aside program arranged via cooperative agreements with farmers in Refugio County. Study plots totaled 93 ha contained in six treatment areas in 1990-91, and 328 ha contained in 24 treatment areas in 1991-92. Treatment areas ranged from 6.9 to 18.2 ha in size. Each year, sorghum fields were selected based on access and size. Participating landowners received \$37-\$50 ha^{-1} depending on prescribed treatment. All study plots were managed and harvested using farming techniques typical of southern Texas (Bremer, 1976), and none of the study plots were grazed by domestic livestock.

Treatments were randomly assigned to treatment areas. Treatments in 1990-91 included (1) normal harvest with stalks left standing until the end of February (harvested-only), (2) normal harvest with stubble shredded within 10 days and left until the end of February (single-shredded), and (3) normally farmed, repeatedly disced following harvest (control treatment). Treatments in 1991-92 included those used in 1990-91 and: (4) normal harvest with stubble shredded within 10 days, and shredded again (5-10 cm high) after second-growth heads matured in October-November (double-shredded); (5) normal harvest with stubble shredded within 10 days, then lightly disced (8-12 cm depth) after the second growth heads matured (shred-disced), and (6) normal harvest with stubble shredded within 10 days, then chisel plowed (8-12 cm depth) after the second-growth heads matured (shred-chisel plowed). The second phase of treatments 3-5 were implemented between 5 and 7 December 1991.

The survey period during August to February 1991-92 was divided into two periods: pre-treatment being prior to implementation of the second phase of treatments 3-5, and post-treatment being from treatment implementation through February.

Grain and forage sampling of study plots began immediately after harvest in mid-August on a monthly schedule until the first week in October, then sampling was biweekly through February. Grain availability was estimated from two randomly located 40.4-m^2 sampling plots within each treatment area (Frederick and Klaas, 1984). The sampling plot was designed to sample a width of six rows of sorghum, the combine width used by farmers in this study. By sampling one full combine width, samples were obtained from all points across one pass of a combine. We sampled the same number of each row type (middle and edge) in case the combine left more waste grain in a certain row type (Baldassarre et al., 1983). Each treatment area was measured, and grid maps were made for each treatment area so study plots could be randomly selected.

All seed-bearing heads of sorghum within each sampling plot were counted during each sampling period. Seed heads included two types, those missed by the previous harvest and on the ground, and standing heads (those still growing on plants that were mature or maturing--turning red in color). Seed heads were designated as those that contained the main stem of the plant. The first ten standing heads and first ten heads on the ground were collected from each sampling plot to estimate grain densities from seed heads. A 1.37-m^2 quadrat within each sampling plot was sampled for loose seeds on the ground (single seeds and parts of seed heads not containing the main stem). All seeds were removed from seed heads and seed head branches and sifted with a 20-mesh sifter to remove all non-seed debris. All seed samples were oven-dried for 48 hours at 50-55°C and weighed to the nearest 0.1 gram and then extrapolated for each 40.4-m^2 sampling plot. Both sample plots in each treatment area were averaged to estimate total sorghum availability in each treatment area biweekly. Total number of seed-bearing heads on the ground in each 40.4-m^2 sampling plot were divided by the number collected in the sample, then multiplied by the dry weight of seeds from the sample heads to estimate available grain on the ground in each sampling plot. The same process was followed to estimate grain densities from standing seed heads. Total grain density was then determined by adding estimated dry weights for loose seeds, ground heads, and standing heads. The two sampling plots in each treatment area were averaged to estimate total grain densities for each treatment area biweekly.

All above-ground green biomass within four 1-m^2 quadrats (two per sampling plot; four per treatment area) was sampled by clipping (Milner and Hughes, 1968). Forage samples were dried at 40-45°C for 72 hours and weighed to the nearest 0.1 gram. Dry weights of forage from all four 1-m^2 sampling quadrats within each treatment area were averaged to estimate total forage available biweekly.

Avian surveys were conducted between one hour after sunrise and 1200 hours within each treatment area prior to grain and forage sampling during each biweekly sampling period. Treatment areas were systematically searched and all bird species were recorded. A bird was considered using a study plot if it was in the sorghum or indirectly using the plot (e.g., insectivorous species feeding on insects over the plots, or raptors hunting prey using the plots). Time of day and percentage of treatment covered with standing water were also recorded.

Differences in total grain densities between harvested-only and single-shredded treatments were compared using *t*-tests (SAS, 1985). Forage availability for all other treatments were compared using a completely randomized one-way ANOVA or two-way ANOVA. If the main effect and/or location by treatment interaction *F*-value were significant ($P < 0.05$), LSD confidence intervals were used to determine which treatments differed (Milliken and Johnson, 1984).

Birds were placed into four groups (geese, ducks, upland game, and nongame) because sample sizes of individual species were not adequate for analyses (Ballard, 1993: Table 10). All bird survey data from study plots were converted to densities (numbers ha^{-1}) to standardize for different sized treatment areas. Treatment comparisons for bird group density data were analyzed using the same procedures as for forage data. In addition, bird species richness data were analyzed using the GLM procedure of SAS, and comparisons among treatments were tested with LSD mean separation tests. Bird species diversity was compared among treatments without statistical testing.

RESULTS

Grain and Forage Availability

Due to limited acreage in the first year and wet conditions preventing farmers to complete all treatments during the second year, replication of all five treatment types at every location was not possible. Thus, inability to complete the second phase of double-shredded, shred-disced, and shred-chisel plowed treatments in several study fields were limited to one or two locations (Table 1). Wet conditions also

Table 1. Number of treatment areas and distribution of treatments among locations in Refugio County, Texas, 1990-91 and 1991-92.

Year	Location	Treatments	$n^{\dagger}$
1990-91			
	Bauer	Harvested-only	1
		Single-Shredded	1
		Control	1
	Gillespie	Single-shredded	1
	Mathis	Single-shredded	1
	Wendlend	Harvested-only	1
1991-92			
	Ermis	Single-shredded	1
		Control	1
	Franke	Single-shredded	1
		Control	1
	Teril	Harvested-only	3
		Double-shredded	2
		Shred-disced	3
		Shred-chisel plowed	2
		Control	1
	Welder	Single-shredded	5
		Double-shredded	2
		Shred-disced	1
		Control	1

†Number of treatment areas

accelerated decomposition of sorghum seeds; by the time second phase treatments were completed in December 1991, no sorghum remained in any treatment areas. For this reason, data analyses on sorghum availability is restricted to harvested-only and single-shredded treatments.

Sorghum availability (dry weight) gradually declined from October-December in 1990-91 (Fig. 2), when most seed heads had shattered, leaving seeds on the ground. Seeds and seed heads that had been on the ground from harvest had mostly decomposed or had been consumed by the end of December. Harvested-only treatments produced a second growth seed head 3-4 weeks earlier than single-shredded treatments, and therefore had more grain available earlier. Second growth seed heads in single-shredded treatments matured in mid-October in both years. The dry winter during 1990-91 in Refugio County most likely extended the longevity of seeds; since seeds were not wet as often, moisture-related decomposition was reduced. Low amounts of sorghum were available through February 1991. All available sorghum had decomposed by the end of November 1991 (Fig. 2). Above-normal rainfall accelerated decomposition of grain. Prolonged saturation of many study sites caused growing seed heads still on the stalks to mildew and rot.

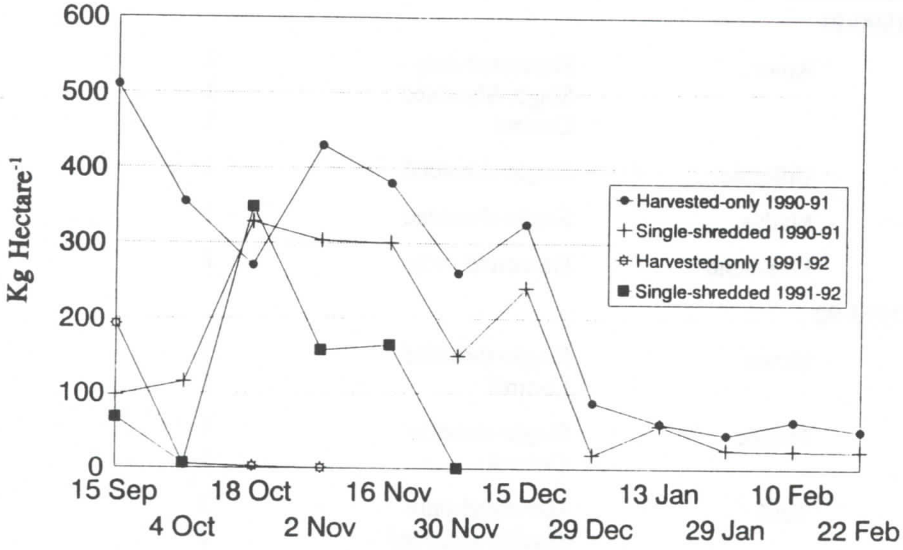

Figure 2. Post-harvest sorghum availability for harvested-only and single-shredded treatments during September to February 1990-91 and 1991-92.

Total grain availability did not differ ($P > 0.05$) between years in harvested-only or single-shredded treatments. Single-shredded treatments contained more ($F = 16.73$; 1,4 df; $P = 0.015$) grain following harvest than the controls. The location by treatment interaction was not significant ($P = 0.084$). Grain was only found in small quantities during the first sampling period in control areas during 1991-92, after which the grain had decomposed.

Forage availability (dry weight) sharply increased in mid-October 1990 due to precipitation received in several treatment areas (Fig. 3). By the end of December 1990, all green vegetation within treatments and the control had dried and died. Forage persisted longer in all treatments except harvested-only during 1991-92 (Fig. 4).

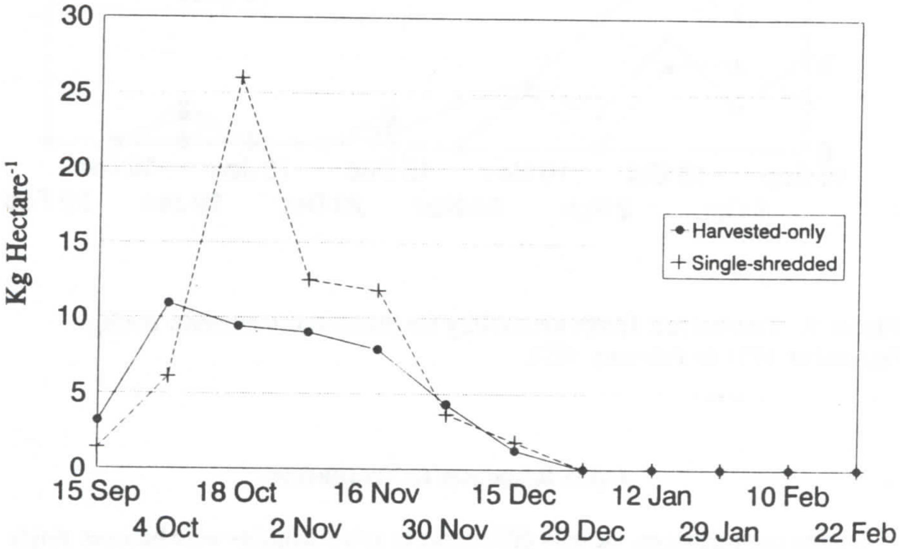

Figure 3. Post-harvest forage availability for prescribed treatments during September 1990 to February 1991.

Availability of forage did not differ between years for harvested-only treatments ($P = 0.758$) or single-shredded treatments ($P = 0.906$). Single-shredded treatments produced more forage ($n = 8$, $\bar{x} = 5.10$ kg ha^{-1}, SE = 11.84) than the controls ($n = 4$, $\bar{x} = 0.66$ kg ha^{-1}, SE = 7.28) ($F = 10.57$; 1,4 df; $P = 0.031$). The location by treatment interaction was not significant ($P = 0.140$). Saturated ground and cold conditions limited vegetation growth during post-treatment; we observed no differences ($P > 0.10$) among treatments. Forage availability in controls was higher during the wet conditions of 1991-92 than during 1990-91.

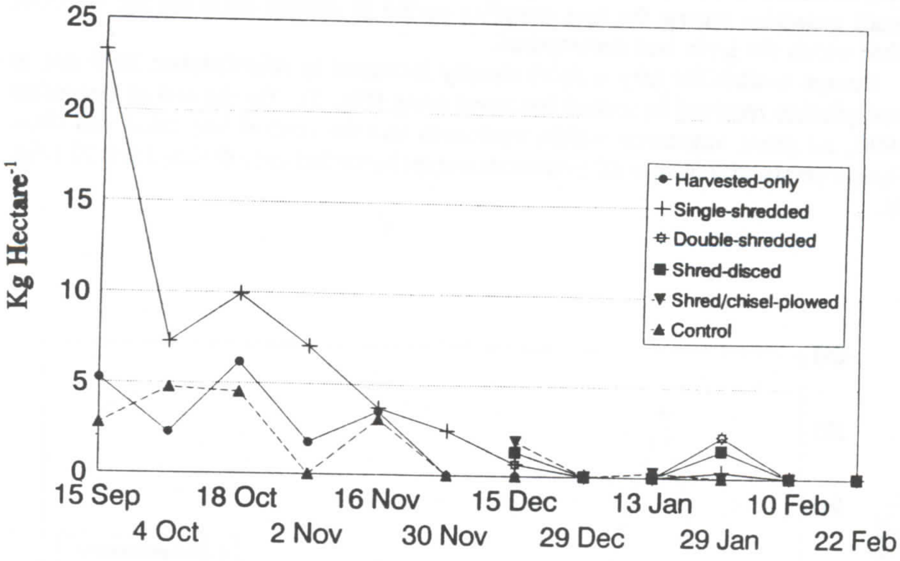

Figure 4. Post-harvest forage availability for prescribed treatments during September 1991 to February 1992.

Avian Responses to Treatments

During pre-treatment, the only differences in avian densities were between single-shredded treatments and controls. Both upland game birds (which consisted primarily of mourning doves and northern bobwhites) ($\bar{x}$ = 1.7 ha^{-1}, SE = 0.2) and nongame birds ($\bar{x}$ = 23.1 ha^{-1}, SE = 4.8) were more abundant ($P < 0.05$) in single-shredded treatments than controls (upland game birds, $\bar{x}$ = 0.6 ha^{-1}, SE = 0.4; nongame birds, $\bar{x}$ = 4.9 ha^{-1}, SE = 2.2). The location by treatment interactions were not significant for either upland game birds ($P = 0.189$) or nongame birds ($P = 0.261$). There were no differences ($P > 0.05$) among any other treatment comparisons in abundance, bird species richness, or diversity during pre-treatment.

Densities of ducks observed using the Welder study site were 5 times higher in double-shredded than single-shredded treatments (Table 3). No ducks were observed in the shred-disced treatment or control. Goose densities in double-shredded treatments were 7-8 times higher than in any other treatment and nearly 12 times higher than in the control (Table 4). Density for upland game birds in the shred-disced treatment on the Welder study site was 11 times higher than in single-shredded treatments and 7 times higher than in the control (Table 5). Upland game bird densities for double-shredded treatments averaged 6 times higher than in single-shredded treatments. Nongame bird densities in single-shredded treatments were 88 times higher than the controls (Table 6). The location by treatment interaction was not significant ($P = 0.095$). Nongame bird densities in single-shredded and double-

Table 2. Locations in Refugio County, Texas, involved in treatment comparisons for sorghum, forage, and bird survey analyses during September to February 1990-91 and 1991-92.

Comparison	Treatments	Years	Locations
1	Harvested-only vs Single-shredded	1990-91	Bauer
		1991-92	Ermis
		1991-92	Franke
		1990-91	Gillespie
		1990-91	Mathis
		1991-92	Teril
		1991-92	Welder
		1990-91	Wendlend
2	Single-shredded vs Control	1990-91	Bauer
		1991-92	Ermis
		1991-92	Franke
		1991-92	Welder
3	Double-shredded vs Shred-disced vs Control	1991-92	Teril
		1991-92	Welder
4	Harvested-only vs Double-shredded vs Shred-disced vs Shred-chisel plowed vs Control	1991-92	Teril
5	Single-shredded vs Double-shredded vs Shred-disced vs Control	1991-92	Welder

shredded treatments on the Welder study site were 3-4 times higher than in shred-disced treatments, and 63-83 times higher than in the control (Table 6).

Single-shredded treatments averaged 1.5 times more species of birds over the entire sampling period (September-February) than harvested-only treatments during both years. Single-shredded treatments averaged almost 2 times the number of species that occurred in the controls over the entire sampling period in both years. The only difference among treatments in numbers of species (richness) observed occurred on the Welder study site ($F = 8.26$; 3,5 df; $P = 0.022$) where 1.4 times more ($P < 0.05$) and 2.5 times more ($P < 0.05$) species of birds were observed in double-shredded treatments than in single-shredded treatments or the control, respectively. Bird species richness in shred-disced treatments were 1.3 times higher ($P < 0.05$) than in single-shredded treatments and 2.3 times higher ($P < 0.05$) than the control.

Table 3. Mean densities (number ha^{-1}) and standard errors (SE) for numbers of ducks on the Welder study plots during post-treatment (December-February) surveys 1991-92, in Refugio County, Texas.

Comparison†	Treatments	n	$\bar{x}$	SE
5§	Single-shredded	5	7.36b‡	4.01
	Double-shredded	2	39.10a	11.48
	Shred-disced¶	1	0.00b	
	Control¶	1	0.00b	

†Treatment comparisons not included where no ducks were observed.

‡Means having same letter are not different ($P > 0.10$) using Scheffe's procedure.

§CR 1-way ANOVA; no treatment effect ($F = 5.30$; 3,5 df; $P = 0.052$); MSE = 116.94.

¶No standard error due to sample size = 1.

Table 4. Mean densities (number ha^{-1}) and standard errors (SE) for numbers of geese in study plots during post-treatment surveys (December-February) 1990-91 and 1991-92, in Refugio County, Texas.

Comparison†	Treatments	n	$\bar{x}$	SE
2§	Single-shredded	4	3.31a‡	1.82
	Control	4	1.30a	0.99
5¶	Single-shredded	5	4.63b	2.33
	Double-shredded	2	38.89a	13.45
	Shred-disced#	1	5.41b	
	Control#	1	3.25b	

†Treatment comparisons not included were those treatments where no geese were observed.

‡Means within each comparison with same letters are not different ($P > 0.05$) using Scheffe's procedure.

§CR 2-way ANOVA with location as 2nd factor; no interaction ($F = 0.03$; 3,4 df; $P = 0.9737$), no treatment effect ($F = 0.003$; 1,4 df; $P = 0.9547$), MSE = 27.17, $R^2 = 0.2926$.

¶CR 1-way ANOVA; treatment effect ($F = 6.51$; 3,5 df; $P = 0.035$), MSE = 94.10.

#No standard error due to sample size = 1.

Table 5. Mean densities (number ha^{-1}) and standard errors (SE) for numbers of upland game birds on study plots during post-treatment surveys (December-February) in Refugio County, Texas during 1990-91 and 1991-92.

Comparison	Treatments	n	$\bar{x}$	SE
1[‡]	Harvested-only	3	0.28a[†]	0.12
	Single-shredded	5	0.62a	0.37
2[§]	Single-shredded	4	0.09a	0.07
	Control	4	0.11a	1.73
3[¶]	Double-shredded	4	1.26a	0.69
	Shred-disced	5	6.04a	3.16
	Control	2	3.76a	3.61
4[#]	Harvested-only	3	0.40a	0.22
	Double-shredded	2	1.92a	1.41
	Shred-disced	3	7.69a	3.81
	Shred-chisel plowed	2	0.47a	0.02
	Control[††]	1	7.37a	
5[‡‡]	Single-shredded	5	0.10c	0.10
	Double-shredded	2	0.60ab	0.01
	Shred-disced	1	1.08a	
	Control	1	0.15bc	

[†] Means within each comparison having same letter are not different ($P > 0.05$) using Scheffe's procedure.

[‡] CR 1-way ANOVA; no treatment effect ($T = 0.694$; df = 6; $P = 0.514$).

[§] CR 2-way ANOVA with locations as 2nd factor; no interaction ($F = 0.01$; 2,4 df; $P = 0.986$), no treatment effect ($F = 0.06$; 1,4 df; $P = 0.823$), MSE = 0.049.

[¶] CR 2-way ANOVA with locations as 2nd factor; no interaction ($F = 0.38$; 2,4 df; $P = 0.709$), no treatment effect ($F = 0.41$; 2,4 df; $P = 0.687$), MSE = 22.74.

[#] CR 1-way ANOVA; no treatment effect ($F = 1.96$; 4,6 df; $P = 0.220$), MSE = 15.21.

[††] No standard error due to sample size=1.

[‡‡] CR 1-way ANOVA; treatment effect ($F = 8.50$; 3,5 df; $P = 0.021$), MSE = 0.040.

Table 6. Mean densities (number ha^{-1}) and standard errors (SE) for numbers of nongame birds in study plots during post-treatment surveys in Refugio County, Texas, December to February 1990-91 and 1991-92.

Comparison	Treatments	n	$\bar{x}$	SE
1[‡]	Harvested-only	3	18.45a[†]	6.77
	Single-shredded	5	9.68a	4.03
2[§]	Single-shredded	4	14.09a	2.93
	Control	4	0.16b	0.07
3[¶]	Double-shredded	4	18.90a	4.00
	Shred-disced	5	20.69a	4.74
	Control	2	3.53a	3.24
4[#]	Harvested-only	3	18.31a	11.25
	Double-shredded	2	13.67a	6.45
	Shred-disced	3	25.80a	19.55
	Shred-chisel plowed	2	10.16a	6.20
	Control[‡‡]	1	6.77a	
5[††]	Single-shredded	5	18.32a	1.49
	Double-shredded	2	24.14a	0.10
	Shred-disced[‡‡]	1	5.38b	
	Control[‡‡]	1	0.29c	

[†] Means within each comparison having same letters are not different ($P > 0.05$) using Scheffe's procedure.

[‡] CR 1-way ANOVA; no treatment effect ($T = 1.201$; df = 6; $P = 0.275$).

[§] CR 2-way ANOVA with locations as 2nd factor; no interaction ($F = 4.49$; 2,4 df; $P = 0.095$); treatment effect ($F = 10.73$; 1,4 df; $P = 0.031$), MSE = 11.07.

[¶] CR 2-way ANOVA with locations as 2nd factor; no interaction ($F = 0.35$; 2,4 df; $P = 0.725$), no treatment effect ($F = 0.27$; 2,4 df; $P = 0.776$), MSE = 594.38.

[#] CR 1-way ANOVA; no treatment effect ($F = 0.21$; 4,6 df; $P = 0.921$) MSE = 535.61.

[††] CR 1-way ANOVA; treatment effect ($F = 19.52$; 3,5 df; $P = 0.003$), MSE = 8.86.

[‡‡] No standard error due to sample size=1.

Bird species richness and diversity were summarized across locations (Table 7) to better show patterns among treatments, although statistical tests for these pooled data were not appropriate. Mean number of species observed during post-treatment was highest for the double-shredded treatment during 1991-92. Bird species diversity averaged higher in all treatments than in controls. The five treatments had average diversity values ranging from 1.23-1.87, while the controls had an average diversity value of 0.76.

Table 7. Mean diversity and species richness, and standard errors (SE), for five treatments and control (all locations pooled) during post-treatment surveys on study plots in Refugio County, Texas, December to February 1990-91 and 1991-92.

Treatment	Diversity† $\bar{x}$	Diversity† SE	Species richness $\bar{x}$	Species richness SE	n‡
Harvested-only	1.24	0.17	7.67	1.53	5
Single-shredded	1.59	0.16	10.80	1.64	10
Double-shredded	1.87	0.14	11.50	4.20	4
Shred-disced	1.42	0.16	8.75	3.86	4
Shred-chisel plowed	1.23	0.21	6.00	0.00	2
Control	0.76	0.19	5.50	0.71	5

†Shannon index was calculated for each treatment area.
‡n = number of treatment areas.

DISCUSSION

Combine efficiency, moisture content of grain, insects, and disease are factors that determine waste grain availability during harvest. Waste grain availability following harvest is affected by several other factors, the most obvious being post-harvest cultivation practices. Nearly all cropland in southern Texas is cultivated throughout fall and winter if weather permits. Fall cultivation buries available seed, and the degree of cultivation determines how much grain will remain available. Warner et al. (1985) found that even intermediate tillage systems reduced waste corn and soybean abundances by 90% and 74%, respectively.

In southern latitudes where winters are mild, precipitation following harvest can affect grain availability. Moisture can cause sprouting of sorghum seeds within 24 hours, and accelerate decomposition of grain that is on the ground. Seed heads still on the plants can also be affected by prolonged saturation of soils. Several study sites during the wet fall of 1991-92 were saturated for an extended period of time (2 weeks or more). Seed heads on the plants grew a fungus and rapidly rotted.

The two years of the study show results of dry and wet conditions. During the dry conditions of 1990-91, some grain remained available through February. However, above-normal precipitation during 1991-92 accelerated moisture-related decay of grain and all available grain had disappeared by the end of November 1991.

Forage availability after harvest is also affected by precipitation. Precipitation is not only required for vegetation growth, but also prevents farmers from cultivating fields. Disced fields throughout Refugio County were void of vegetation throughout fall and winter 1990-91, and our controls had no forage growth. Forage growth was evident in most disced fields throughout the county during 1991-92, and our controls had noticeable growth through November. Forage growth was lower in treatment areas that contained heavy harvest residues, probably because the residue prevented light penetration to the soil.

Experimental studies suggested that the double-shredded treatment was the most productive way to manage sorghum for waterfowl. Shred-disced treatments were mostly used by upland game birds, and nongame birds benefitted the most from single-shredded and double-shredded treatments. Double-shredded or shred-disced treatments provided the best cost benefit because they are intermediate steps in current post-harvest farming practices in southern Texas and are recommended for state and federal refuge croplands and set-aside lands in southern Texas.

All treatments were either harvested-only or single-shredded during pre-treatment; both treatments were similar in structure, with seed heads on standing stalks. Thus, with similar structure and no difference in grain availability, it was not surprising to find no differences in bird use. During post-treatment, there were no differences in grain or forage availability among treatments, so stubble structure appeared to be the factor affecting preference of treatments by birds. When waterfowl were found in double-shredded and shred-disced treatments and controls, they were typically found far from any cover, including standing stubble. When waterfowl occurred in treatments with standing stalks, they were in areas where the stalks had been flattened by water inundation or trampling by wild mammals.

MANAGEMENT IMPLICATIONS

Sorghum management for waterfowl and other wildlife can be beneficial, but will be practical only if valuable to farmers. Leaving stubble or any residue on fields following harvest is incompatible with current cropland management strategies of farmers in south Texas. Every farmer that planted sorghum in Refugio County was given the opportunity to leave their set-aside stubble stand after harvest for \$37-\$50 ha^{-1}. Most farmers were reluctant to change from their present practice of clean farming. According to farmers in the Coastal Bend, crop yields would be reduced about 50% (a loss of approximately \$125 ha^{-1}) the following year if fields were not kept clean of residue and green vegetation. However, several studies have shown reduced tillage practices for grain sorghum can increase crop yields over conventional tillage and improve the physical condition of the soil (Bremer, 1976; Unger et al., 1989; Matocha et al., 1990; Landivar et al., 1990). These increases in yields are brought about by increases in the storage of soil moisture due to residues left on the fields. Farmer education and research showing advantages of crop residue management through limited and/or conservation tillage practices are needed in order to change land management practices for both soil conservation and wildlife benefits.

Our experimental studies showed double-shredding to be the best treatment for both ducks and geese. However, hunting migratory birds on or near double-shredded fields may be perceived as baiting, a violation of federal game laws (T. Mason, U.S. Fish and Wildl. Serv. Spec. Agent, pers. commun.). Managers contemplating use of double-shredding as a sorghum-management tool should consider this baiting issue if nearby hunting is likely. In areas where double-shredding may not be appropriate, the shred-disced treatment was the next best treatment.

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Irrigation Technology Adoption in the Texas High Plains

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ABSTRACT

As groundwater tables decline and irrigation costs increase, irrigators are expected to adjust their crop patterns, irrigation systems, and production practices. This study provides insight into the efficient path of irrigation technology adoption and examines the implications associated with this process. It was shown that (1) the efficient crop pattern is related to the groundwater supply condition, (2) declines in the proportion of high water requirement crops produced are rapid with high pumping lift and thin saturated thickness, and (3) declines in saturated thickness appear to have a greater impact on crop pattern and irrigated acreage than do increases in pumping lift. The rate of adoption is expected to be higher with more abundant groundwater.

KEYWORDS: groundwater use, groundwater depletion, LEPA, water use efficiency

Irrigation has played an important role in the development and growth of agriculture in the United States. Irrigated farms contribute proportionally more to crop production than do dryland farms. For instance, in 1982, irrigated farms comprised only 12% of all farms, yet they produced nearly one-third of the total value of agricultural products (Moore et al., 1987). Irrigation is particularly important to the agricultural economy in the semi-arid area of the High Plains: a large land resource area within the Great Plains region of the United States. This region is one of the most heavily irrigated areas in the United States, comprising some 20% of the national irrigated acreage. In the High Plains region, irrigation is essential in agricultural production because rainfall is either unreliable or insufficient. The main water source of irrigation in the High Plains region is the Ogallala Aquifer, one of the more extensive and important interstate aquifers in the United States.

In the High Plains region, rapid expansion of irrigation practices using groundwater began after World War II. In 1982, about 17 million acres of cropland were under irrigation, and the total annual water withdrawal was 21 million acre feet (Moore et al., 1987). Because recharge is insignificant compared to withdrawals, the continued overdraft has resulted in declines of groundwater tables from 50 feet to 200 feet in some areas in the High Plains region (High Plains Associates, 1982). The per unit energy cost of groundwater pumping per foot of lift has increased dramatically since the early 1970s. Sloggett (1985) documented increases in energy costs of 182% for electricity to 700% for natural gas between 1974 and 1983. Thus, the increased pumping lift and decreased well yields, coupled with rising energy costs, have resulted in significant increases in the production cost of irrigated crops in the High Plains.

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Given a groundwater stock, the rate at which the groundwater supply diminishes is determined by the amount of withdrawal, the technology of exploitation, and the input-output price relations. Due to the continued overdraft of groundwater in the Texas High Plains (THP) region, in which about 30% of pre-development storage, on the average, has been depleted, this region has become the most critical groundwater depletion area in the Ogallala Formation (Gutentag et al., 1984).

Recent studies have highlighted some of the factors which affect irrigation technology adoption and the linkages between farmers' crop choices and irrigation technology investment decisions. Lichtenberg (1989) analyzed the relationships among irrigation technology investments, cropping patterns, and land quality factors. Caswell and Zilberman (1985), Negri and Brooks (1990), Casterline et al. (1989), and Dale et al. (1989) examined the impacts of factors such as land quality, water sources, relative prices of irrigation inputs and outputs, and government program participation on the adoption of advanced irrigation technologies.

The objective of this study was to derive dynamically optimal rates of groundwater use in agriculture which maximize the net present value of returns to the agricultural producer's groundwater stock, land, capital, management, risk and overhead under alternative scenarios. Lubbock County was used as a representative area within the THP. In particular, this study included the determination of dynamically efficient crop patterns, irrigation technologies, and groundwater use through time.

METHODS AND PROCEDURES

A dynamic framework whose components included a bio-simulation model of crop growth and a firm level dynamic programming (DP) model were used to derive optimal decision rules of groundwater use over time under alternative scenarios. The bio-simulation crop growth model used was the Erosion/Productivity Impact Calculator (EPIC) developed by Williams et al. (1984). This model was used to simulate data on crop yield-water responses under alternative combinations of cropping practices and irrigation technologies. The crop yield-water data simulated were used to estimate yield-water production functions using regression analysis and were used in the dynamic optimization models (Feng, 1992). The major underlying assumption of the DP models was that irrigators consider the total returns derived from irrigation over a long planning horizon. A 50 year planning horizon was used. These models are capable of determining optimal groundwater use, cropping pattern, cropping practice, irrigation technology, and marginal user costs while adjusting groundwater availability and extraction cost. It is important to point out, that there has been considerable interest on the intraseasonal aspects of irrigation decisions. For those interested readers, Dinar and Knapp (1986) and Bryant et al. (1993) provide dynamically optimal intraseasonal decision rules of irrigation water use under saline conditions and under stochastic weather patterns, respectively.

The crops considered in this study were cotton, grain sorghum, and corn. These three crops encompass 91% of the total irrigated area and 47% of the non-irrigated area in Lubbock County. Numerous tillage practices and irrigation technologies exist, but the ones included in the optimization models were those which were widely used or showed some acceptance in the study's region. Tillage practices considered in this study included conventional and conservation tillage.

Conventional tillage was applied to all crop enterprises, while conservation tillage was only applied to cotton production. The conservation tillage method considered was a terminated wheat and cotton (TWH-CO) rotation. Six irrigation technologies were considered in this study. These included conventional furrow (CF), improved furrow (IF), sprinkler-high pressure (SH), sprinkler-drop (SD), low energy precision application (LEPA), and dryland farming. The optimization models in this study were formulated on a per acre basis with percentages being used to represent the proportion of a crop under a given tillage practice and irrigation technology.

The operating cost data used for the crops were the average projected costs for the 1981-1990 period from the Texas Crop Enterprise Budgets for the Texas South Plains District (Texas Agricultural Extension Service, 1981-1990). These budgets included the basic operating costs for dryland and irrigated production, which include fertilizer, seed, herbicide, insecticide, machinery, harvesting costs, and irrigation well costs. The commodity prices used were the ten year average prices received by farmers for the 1981-1990 period as reported by the Texas Agricultural Statistics Service (Texas Department of Agriculture, 1981-1990).

The per unit cost of pumping water is a function of pumping lift and well yield. Well yield decreases as the saturated thickness of the aquifer decreases. Therefore, the per unit cost of pumping water is a function of pumping lift and saturated thickness. Also, to evaluate the effect of pumping groundwater on the water stock, recursive equations, which consider the intertemporal adjustment of water availability, are necessary. All the assumptions and relationships used in deriving the hydrologic equations which describe the dynamics of the per unit cost of pumping water and the aquifer are described in Feng (1992).

Three additional constraints were used in the optimization models. The first constraint was a constraint on operating capital. Operating capital was assumed to be available from two sources. The first source was a fixed value of $250 per acre in each period of operation. The second source was the portion of the previous year's income which exceeds the average per acre return to land, management, and overhead estimated at $40 (Texas Agricultural Extension Service, 1981-1990). The second constraint was land availability. The third constraint was a pumping capacity constraint at each time period.

Specification of the Dynamic Optimization Model

The objective function used in the models was that of maximizing the net present value of returns to land, management, groundwater stock, risk, and investment in irrigation systems. Net returns are calculated as gross returns minus total costs. The total costs consist of variable costs and fixed costs. The variable costs are the costs directly associated with the level of the control variables. These are the costs of pumping groundwater, investment and maintenance costs associated with the cropping practices, and investment and maintenance costs of the various irrigation systems. Given this information, a net return function in time *t* can be constructed as:

$$\mathrm{NR}_t = \Sigma_i\, \Sigma_j\, \Sigma_k\, \Theta_{ijkt}\{\mathrm{P}_i \mathrm{Y}_{ijkt}[\mathrm{WA}_{ijkt}(\mathrm{WP}_{ijkt})]-\mathrm{C}_{ijk}(\mathrm{WP}_{ijkt},\mathrm{X}_t,\mathrm{ST}_t)\} \tag{1}$$

where *i* represents the crops grown; *j* represents the cropping practices used; *k* represents the irrigation technologies used; Θ_{ijkt} is the percentage of crop *i* produced with cropping practice *j* and irrigated by irrigation technology *k* in time *t*; P_i is the price of crop *i*; WA_{ijkt} and WP_{ijkt} are per acre irrigation water available to the crop and groundwater pumped, respectively, for crop *i* using *j*th cropping practice and *k*th irrigation technology at time *t*; $Y_{ijkt}[.]$ is the per acre yield production function of crop *i* using the *j*th cropping practice and the *k*th irrigation technology at time *t*; C_{ijk} is the total cost per acre associated with the production of the *i*th crop using the *j*th cropping practice and the *k*th irrigation technology; X_t is the pumping lift at time *t*; and ST_t is the saturated thickness of the groundwater stock at time *t*.

The objective function to be optimized for the fifty-year planning horizon is:

$$\text{MAX NPVR} = \Sigma^{50}_{t=1} NR_t(1+r)_{-t} \tag{2}$$

where NPVR is the net present value of returns, and *r* is the discount rate. The control variables in this optimization problem are: WP_{ijkt} and Θ_{ijkt}.

Substituting equation (1) into (2) and adding all the relevant constraints, the empirical dynamic programming model is:

$$\text{MAX NPVR} = \Sigma_i\, \Sigma_j\, \Sigma_k\, \Sigma_t\, \Theta_{ijkt}\{P_i Y_{ijkt}[WA_{ijkt}(WP_{ijkt})] - C_{ijk}(WP_{ijkt},X_t,ST_t)\}(1+r)^{-t} \tag{3}$$

Subject to:

$$ST_{t+1} = ST_t - [(1 - a)(\Sigma_i\, \Sigma_j\, \Sigma_k\, \Theta_{ijkt}{*}WP_{ijkt}) - R]\ K/As, \tag{4}$$

$$X_{t+1} = X_t + [(1 - a)(\Sigma_i\, \Sigma_j\, \Sigma_k\, \Theta_{ijkt}{*}WP_{ijkt}) - R]\ K/As, \tag{5}$$

$$\Sigma_i\, \Sigma_j\, \Sigma_k\, WP_{ijkt} \leq 28.28{*}(ST_t/210)^2 \text{ for all t,} \tag{6}$$

$$\Sigma_i\, \Sigma_j\, \Sigma_k\, \Theta_{ijkt} \leq 1 \quad \text{for all t,} \tag{7}$$

$$\Sigma_i\, \Sigma_j\, \Sigma_k\, C_{ijkt} \leq 250 + (NR_{t-1} - 40) \text{ for all t,} \tag{8}$$

$$\Sigma_i\, \Sigma_j\, \Sigma_k\, C_{ijkt} = FC_{ijk} + HC_{ijkt} + PC_t + PEC_{ijkt} \tag{9}$$

$$PEC_{ijkt} = IC_{ijk}\ 1/[125 - 1.5(ST_t - S_o)], \tag{10}$$

$$PC_t = 0.0014539{*}(X_t + (3.31{*}PSI){*}P)/(PE) \tag{11}$$

$$X_{t=1} = X_1 \tag{12}$$

$$ST_{t=1} = ST_1, \tag{13}$$

$$\Theta_{ijkt} \geq 0\ ,\ WP_{ijkt} \geq 0. \tag{14}$$

The two equations of motion, equations (4) and (5), update the state variables, saturated thickness (ST_t) and pumping lift (X_t). Equations (6), (7), and (8) are the water pumping capacity, land availability, and capital constraints, respectively. Equation (9) is the cost function, where FC_{ijkt} is the fixed cost component (basic operation costs), HC_{ijkt} is the harvest cost, IC_{ijk} is the irrigation system and crop practice investment costs, PC_t and PEC_{ijkt} are the pumping cost without the impact of saturated thickness and pumping cost induced by the change in saturated thickness. Equations (10) and (11) are the definitions of PEC_{ijkt} and PC_t. Equations (12) and (13) are the initial conditions of the aquifer, and (14) ensures that the values of the decision variables are non-negative.

The dynamically efficient solution to this problem is the one which maximizes the net present value of returns by selecting the rates of groundwater pumped for each crop and the combination of crops, cropping practices and irrigation technologies used at each point in time, subject to the constraints. This model was also solved under the assumption of no adoption of new irrigation technologies. This was done by adding two more constraints to the model in equation (3) to (14). These constraints were:

$$\Sigma_i \Sigma_j \Theta_{ijkt} \leq D_k \quad = 1, 2, \ldots, Z \quad \text{for } t = 1, 2, \ldots, 50; \text{ and} \tag{15}$$

$$\Sigma_i \Sigma_k \Theta_{ijkt} \leq H_j \quad = 1, 2, \ldots, n \quad \text{for } t = 1, 2, \ldots, 50 \tag{16}$$

where D_k is the observed percentage of acres of irrigated cropland using the *k*th irrigation technology. H_j is the observed percentage of acres of irrigated cropland using the *j*th cropping practice. Both D_k and H_j do not change over time. The difference between the allocation with and without these constraints represents the impact due to irrigation technology adoption.

RESULTS

The results of the DP models included the optimal crop pattern, irrigation technology adoption, and quantity of groundwater pumped under alternative scenarios analyzed. These scenarios included four different groundwater supply conditions, with and without technological change (Table 1). The Basic model was the DP model under the groundwater supply condition of 150 feet pumping lift and 130 feet saturated thickness, using average prices, assuming flexible irrigation technology adoption, and a 2% discount rate. The other four scenarios of the model were similar to the Basic model (except for indicated changes in Table 1).

Table 1. Definitions of the model scenarios.

Scenarios	Pumping Lift	Saturated Thickness	Irrigation Technology
Basic	150	130	flexible
BasicP1	130	130	flexible
BasicP2	197	130	flexible
BasicS	150	50	flexible
BasicFT	150	130	fixed

Dynamic Optimal Crop Patterns

The optimal and dynamically efficient proportion of land of the different crops under irrigated and dryland conditions of the Basic model as defined in Table 1 are presented in Figure 1. The starting values (the values at time period 1) of the proportion of land by crop represent the current real crop pattern in Lubbock County. The current crop pattern is far from optimal under the specified groundwater supply, capital constraint, and price conditions (Fig. 1). This is because the crop pattern quickly changes to a different crop combination once water use is optimized. Irrigated cotton increases from 40% to 74%, dryland cotton

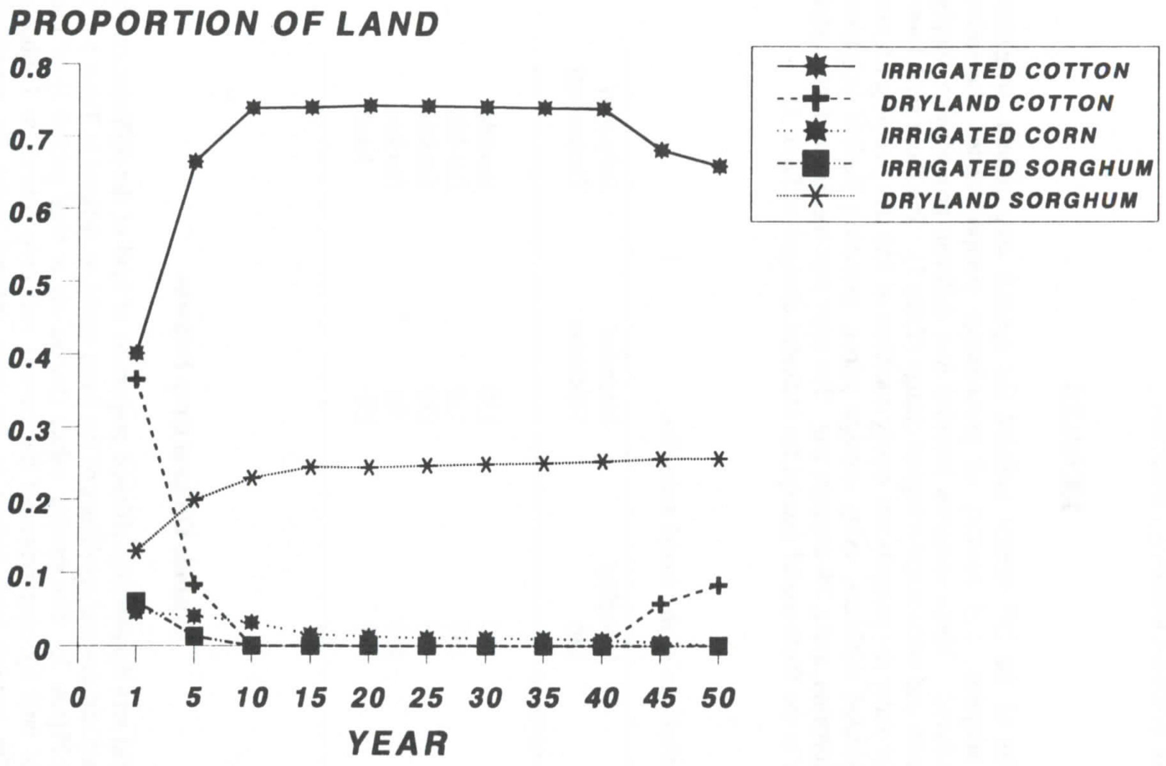

Figure 1. Dynamically optimal crop pattern for the Basic model.

decreases from 36% to 0%, irrigated sorghum drops from 6% to 0%, dryland sorghum increases from 13% to 23%, and irrigated corn decreases from 4.5% to 0% over the first 40 time periods. The optimal crop pattern, as established in the solution, is kept approximately constant over 35 production periods. After the 35th time period, irrigated cotton declines and dryland cotton increases.

This result suggests that the groundwater resource is not utilized efficiently, given the Basic model assumptions. To obtain higher present value of returns from the groundwater stock, irrigated production should be further developed. Also, groundwater scarcity is not likely to be the factor limiting irrigated production in the next 40 years. This result shows that irrigated cotton is superior to irrigated sorghum and corn. Therefore most of the water is allocated to cotton, less to corn, and none to sorghum. The dynamic efficient crop pattern under the specified condition are approximately three quarters of irrigated cotton and one quarter of dryland sorghum. The solution of the BasicP1 and BasicP2 models in which pumping lift is varied indicated similarities in the optimal crop pattern to that of the Basic model. These models' results showed a trend indicating that the greater the pumping lift, the smaller the irrigated crop percentage. The increased pumping cost due to greater pumping lift may affect irrigated acreage in two ways: a) increased variable cost of irrigation results in greater production cost, which causes operational capital to become constrained, thus, less cropland can be irrigated; or b) the increased pumping cost causes irrigated crop production to be less profitable, thus, less money is available for following periods operation and investment on irrigation systems which in turn causes less technological adoption and less percentage of irrigated acreage.

The optimal and dynamically efficient proportion of land of the different crops under irrigated and dryland conditions of the BasicS model, which represents the scenario with poor groundwater storage, indicated a significantly different crop pattern from those of the previous models (Figure 2). That is, the proportion of irrigated acreage drops and dryland cotton increases sharply. Thus, these results suggest that the optimal crop pattern is closely related to groundwater pumping lift and saturated thickness conditions. The reduction in the percentage of high water requirement crops, such as corn, would be faster in areas with higher pumping lift than in the areas with lower pumping lift, and the total irrigated percentage of cropland is reduced as the pumping lift increases. Declines in saturated thickness appeared to have a greater impact on irrigated production than did increases in pumping lift. The results of the BasicFT model indicated that the current crop pattern in Lubbock County is close to the optimal (Figure 3). The differences in the cropping pattern between this model and the Basic model are due to the impact of the irrigation technology adoption assumption. The adoption of irrigation technologies with higher water application efficiency causes an increase in irrigated acreage and the production of crops with high water requirement (as shown by the Basic model). Therefore, the adoption of more efficient irrigation systems does not imply a long-term reduction in groundwater use. If the increase in irrigated acreage was large enough to offset the decrease in per acre groundwater usage, the net result of irrigation technology adoption would be to increase total water use and thus, induce a quicker depletion of the groundwater stock.

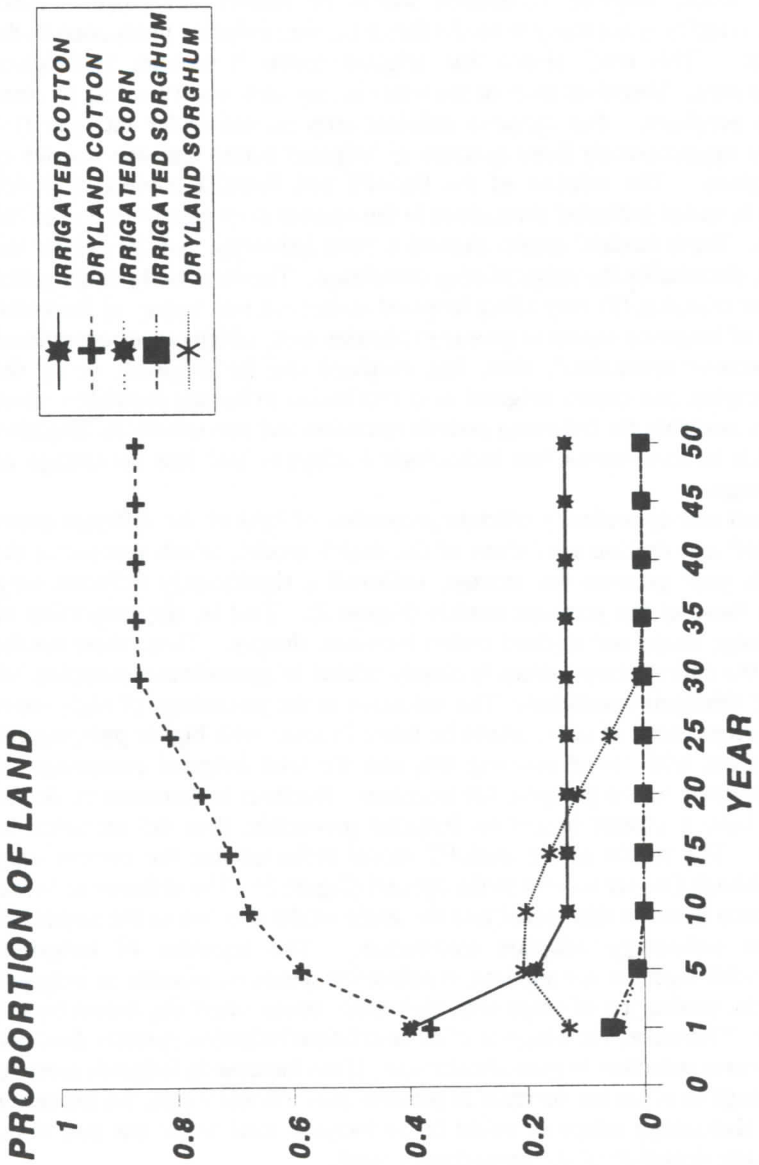

Figure 2. Dynamically optimal crop pattern for the BasicS model.

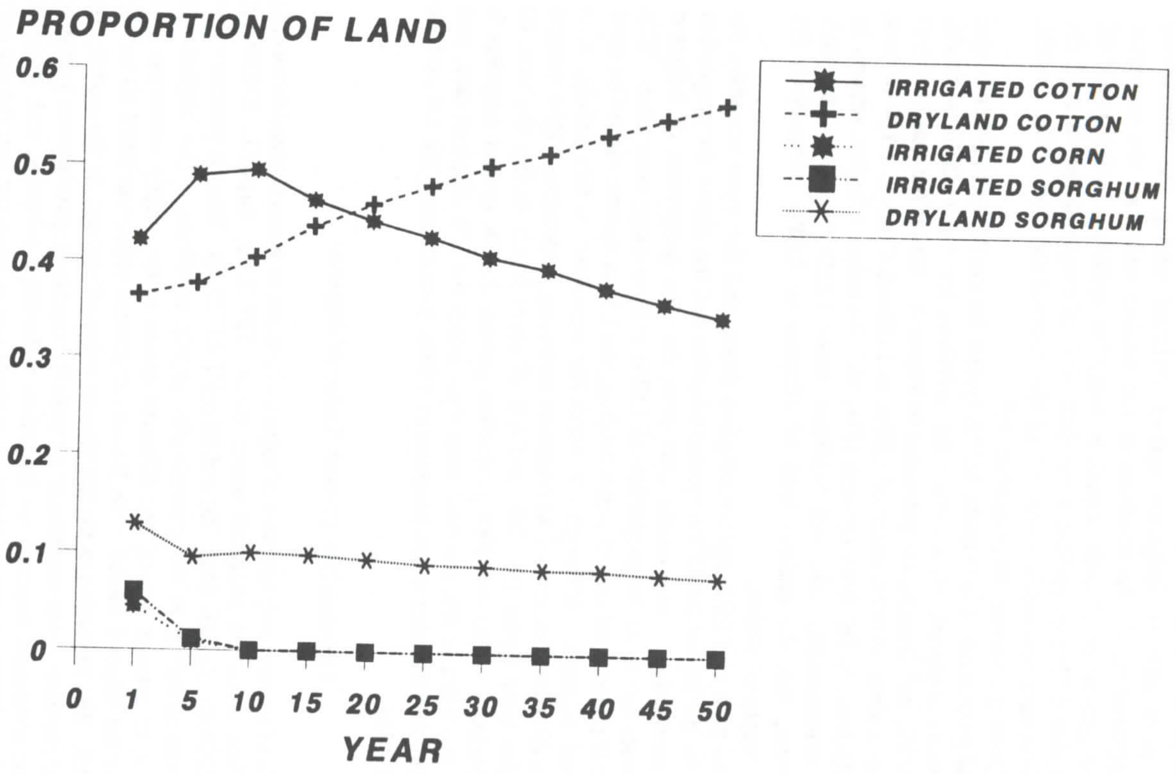

Figure 4. Optimal LEPA system adoption rates under alternative water supply conditions.

Optimal Adoption of Irrigation Technology

The optimal paths of irrigation technology adoption are presented in this section. Among all the irrigation systems and tillage practices included, only three irrigation technologies and one tillage practice, the IF system, the low energy precision application (LEPA) system, dryland farming, and conventional tillage, appeared in the solutions of the DP models under all the scenarios analyzed. The LEPA system, which is the most efficient irrigation system included among the alternatives considered, appeared in all the solutions of the models under all the scenarios analyzed. The general trend with respect to irrigation system adoption under all scenarios was that LEPA comprised more than 60% of cropland for most of the models, the IF system covered less than 5% of the cropland for most of the models, and dryland farming covered the proportion left.

The optimal proportion of land under LEPA system for the different groundwater supply conditions analyzed, which were the solutions for the models of Basic, BasicP1, BasicP2, and BasicS, are presented in Figure 4. Under the assumed cost and capital constraints, current usage of LEPA in Lubbock County, 3.6% of total irrigated production, is far from optimal (Fig. 4). To achieve higher returns to water, land, management, risk, and overhead, more LEPA should be adopted. Notice, however, that the optimal level of adoption of LEPA varies with the groundwater supply condition.

The optimal path of LEPA system adoption shows that the more abundant the groundwater is, the higher the LEPA system adoption and the higher the proportion of irrigated production. The results also show that the proportion of irrigated acreage becomes closer to the proportion of LEPA system usage over time. This indicates that if operational capital is not binding, the LEPA system should be used in all irrigated acreage. Although not explicitly examined in this article, with respect to the discount rate impact on irrigation technology adoption, LEPA system adoption is the same under 2%, 5%, and 8% discount levels during the first 10 production periods. After the 10th production period, LEPA system adoption is lower under the 5% and 8% discount rates than under the 2% discount rate, and there is not much difference in the adoption of LEPA system under the 5% and the 8% discount rates.

Optimal Net Present Value of Returns

The levels of the per acre net present values of returns of the optimization models under the five scenarios analyzed were: Basic, \$2713.70; BasicP1, \$3230.40; BasicP2, \$2250.40; BasicS, \$819.10; and BasicFT \$1775.80. The net present value of returns was sensitive to the groundwater supply condition. The highest net present value of returns among the different groundwater supply scenarios was \$3230.40 for the BasicP1 model. The lowest net present value was \$819.10 for the BasicS model. The reduction in the net present value of returns, as the scarcity on groundwater increases, was contributed by both the increased groundwater pumping cost and the constraint imposed on irrigation technology adoption and irrigated acreage by the scarcity of groundwater. It is important to point out that the per acre net present value of returns differential between the Basic and BasicFT scenarios, \$937.90, represents the impact of irrigation technology adoption on net present value of returns. An increase of over 52% in per acre net present value of returns can be

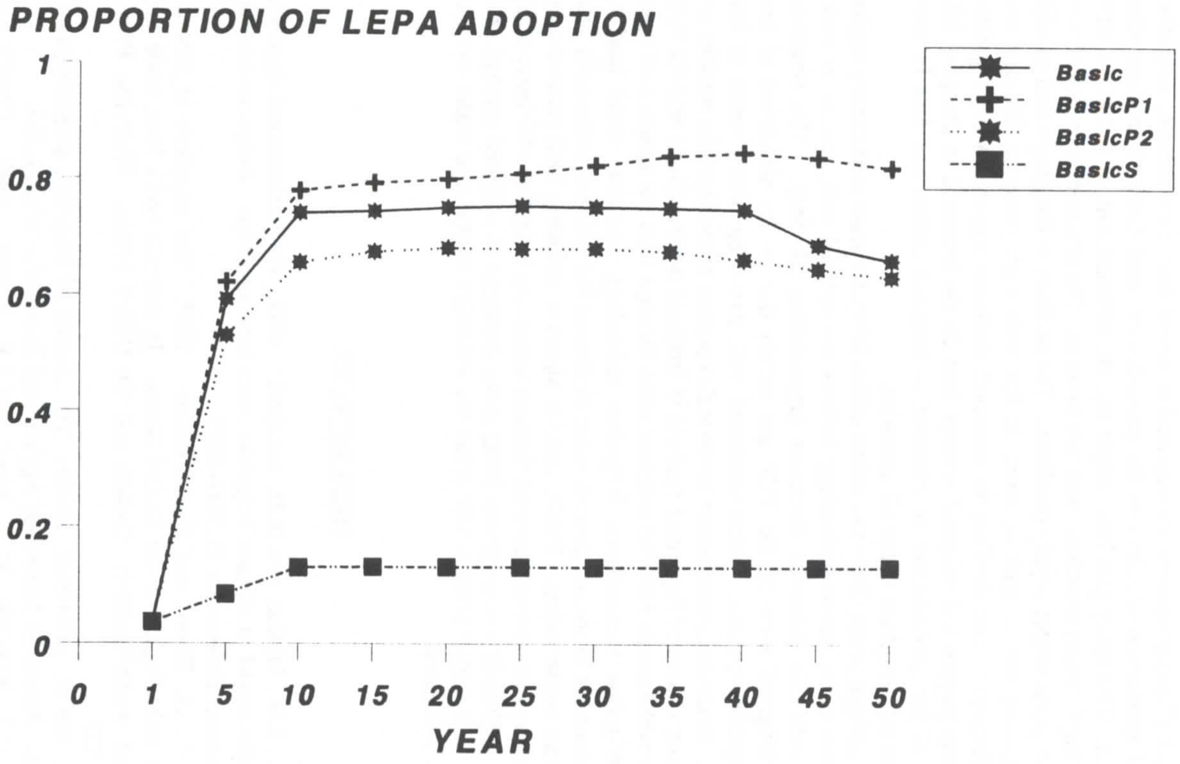

Figure 4. Optimal LEPA system adoption rates under alternative water supply conditions.

expected if agricultural producers are willing to adopt advanced irrigation technologies. This result implies that sizable unrealized returns would be at stake if agricultural producers are unwilling to adopt advanced irrigation systems.

CONCLUSIONS AND POLICY IMPLICATIONS

Texas High Plains producers are expected to adjust their crop pattern, irrigation systems, and production practices as the groundwater level declines and irrigation cost increases. This study provides insight into the efficient path of this adjustment process and implications associated with this process. The efficient crop pattern was related to the groundwater supply condition. The declines in the proportion of high water-requirement crops, such as corn, is fast with high pumping lift and thin saturated thickness. The declines in saturated thickness appear to have greater impact on crop pattern and irrigated acreage than do the increases in pumping lift. Thus, most of the groundwater is allocated to irrigated cotton and less to non-irrigated corn and sorghum under all scenarios.

Irrigated acreage is not likely to decline within 20 to 30 years in the study region if the adoption of irrigation technology follows the optimal path, except in areas underlying with thin saturated thickness (approaching 50 feet). The observed declines in irrigated acres in the THP are mainly due to the utilization of low efficient irrigation systems, which combined with low crop prices result in low profitability. Declining groundwater levels and depletion of the Ogallala Aquifer are not the primary causes of the recent declines in irrigated acres. Given that the total groundwater withdrawals and total irrigated acres increase with the adoption of more efficiency irrigation technologies, irrigation technology adoption could lead to substantial increases in the net present value of returns but will not necessarily lead to groundwater conservation. Public policies aimed at reducing total groundwater withdrawals may not achieve their goal through increasing irrigation efficiency since increases in profitability of irrigation bring about increases in irrigated acreage, and the increase in irrigated acreage will offset the reduction in per acre water use due to increased efficiency.

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Distribution and Abundance of Wetlands in Coastal Texas

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ABSTRACT

Numbers and area of wetlands were estimated in coastal Texas from Galveston Bay south to the Rio Grande during September and November 1992 and January and March 1993 based on a stratified random sample (n = 1,009) of 64.8-ha (quarter-section) plots. We estimated seasonal maximums of 125,187 wetlands in January 1993 and 484,760 ha of wetlands in September 1992.

KEYWORDS: Laguna Madre Initiative Area, Texas Mid-coast Initiative Area, quarter-section survey

Coastal Texas is one of the most important wintering areas for waterfowl in North America (Cain, 1988; Texas Mid-coast Initiative Team, 1990). Coastal marshes and adjacent rice prairie lands provide the most important wintering grounds for waterfowl in the Central Flyway (Buller 1964). Additionally, this area provides important habitat for many other groups of water birds. Several threatened or endangered species inhabit this area, including piping plovers (*Charadrius melodus*) and whooping cranes (*Grus americanus*).

We here define a wetland as any area having hydric soils, hydrophytic vegetation, or inundation during any part of the growing season (Cowardin et al. 1979). One of the first steps in managing wetland habitat and water bird populations is to inventory what is currently available (Leopold, 1933). This provides baseline information for monitoring the effects of future wetland management actions or continued wetland destruction (Dahl, 1990). By identifying the abundance of different wetland types, we can at future dates identify types that are being lost most rapidly.

Tacha et al. (1993) estimated numbers and areas of wetlands in the Chenier Plain of Texas (coastal plains east of Houston). Our objectives were to estimate numbers and areas of wetlands (by type), in the coastal plains of Texas west and south of Houston. Area of wetlands in this study refers to surface area of water.

The study area consisted of two initiative areas (Fig. 1), as delineated by the Gulf Coast Joint Venture (1990). The Texas Mid-coast (TMC) Initiative Area occurred

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from the Nueces River north to Galveston Bay and as far inland as rice production occurs. The Laguna Madre (LM) Initiative Area extended from the Nueces River south to the Rio Grande.

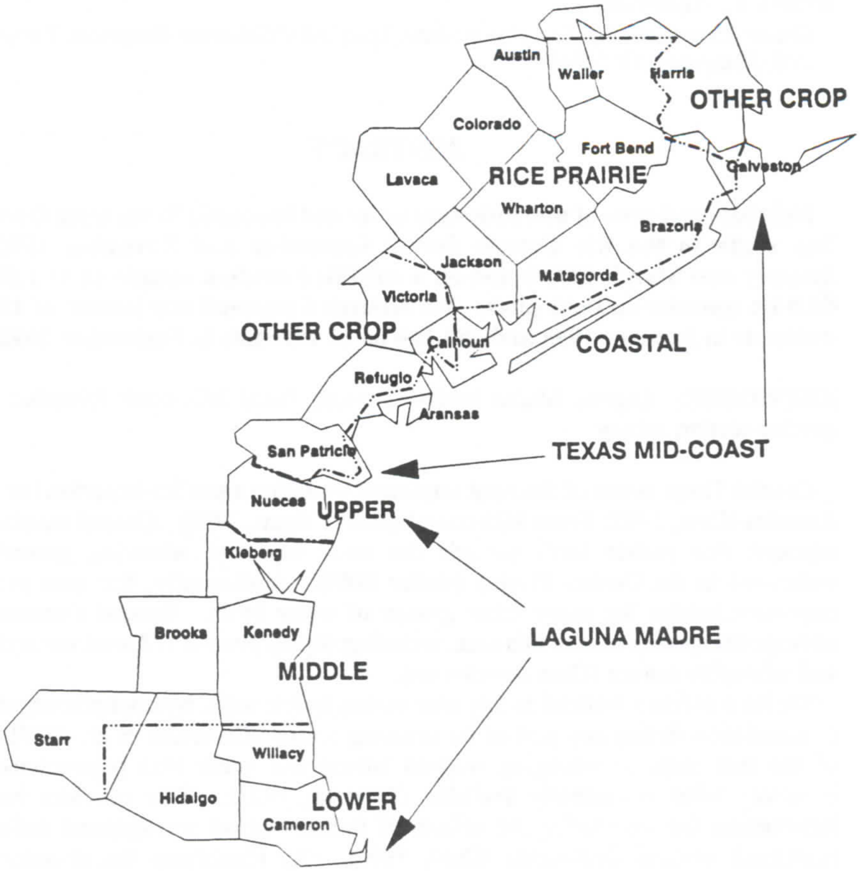

Figure 1. Location of Texas Mid-coast and Laguna Madre initiative areas and strata boundaries for wetland surveys conducted during September and November 1992 and January and March 1993.

The study area encompassed 24 Texas counties covering 5,504,389 ha. The region consisted of sandy plains and coastal prairie in the south and coastal marsh and rice production to the north. Farming and ranching were prevalent throughout. Major agricultural crops were sorghum, cotton, rice, and corn (Tex. Agric. Stat. Serv., 1992).

Topography was nearly level in >95% of the area, with an increase in elevation of 0.2-0.6 m km^{-1} from the coast inland (Westfall, 1975; Laguna Madre Initiative Team, 1990). Elevation ranged from sea level to 122 m above sea level. Soils were somewhat poorly drained, with a surface layer of fine sandy loam above several layers of clay and sandy clay to a depth of 2 m (Westfall, 1975; Lehman, 1984).

Climate classification for the TMC area is subtropical humid, noted for warm summers (Larkin and Bomar, 1983). Average annual high and low temperatures, respectively, are 28 and 13°C. Average annual precipitation ranges from 133 cm in the north to 87 cm in the south (Nat. Fibers Inf. Cent., 1987). Climate is classified as semiarid in the LM area, with frequent droughts in the region (Norwine and Bingham, 1986). Annual rainfall ranges from 80 cm in the north to 55 cm in the south (Larkin and Bomar, 1983), and annual evaporation rates exceed 175 cm. The average annual high and low temperatures are 30 and 16°C, respectively. Climatic conditions during this study were normal (i.e., temperatures and precipitation were near average).

The coastal zone in the TMC is primarily located in the Louisianian estuarine and marine province (Cowardin et al., 1979). This area is characterized by relatively extensive marshes and well-developed barrier islands, with a small tidal range. The LM area is primarily located in the West Indian Estuarine and Marine Province (Cowardin et al., 1979). This province is characterized by a shoreline that is predominantly low-lying limestone with calcareous sands and marls and a small tidal range.

METHODS

The TMC Initiative Area was divided into three strata: rice prairie, coastal, and other crop (Fig. 1). The LM Initiative Area was also divided into three strata: upper, middle, and lower. Strata were based on land practices and major physiographic regions. Descriptions of strata can be found in Anderson (1994) and Muehl (1994).

In 1992-93, we used map coordinates to randomly select 600 and 409 64.8-ha plots (hereafter referred to as quarter-sections) in the TMC and LM Initiative Areas, respectively. Logistics limited our sample size to near 1,000. In the TMC area, Coastal, Rice Prairie, and Other Crop strata were allocated 273, 241, and 86 quarter-sections, respectively. In the LM area, Upper, Middle, and Lower strata were allocated 136, 46, and 227 quarter-sections, respectively. Total quarter-sections in the study area numbered 82,275. The breakdown by strata were coastal (5,486), rice prairie (38,131), lower (10,150), middle (15,208), other crop (10,150), and upper (3,150).

After quarter-sections were randomly selected within strata, trespass permission was obtained or the area was replaced with another random sample. Quarter-sections were surveyed if wetlands or wetland basins occurred. Similar stratified random sample surveys of quarter-sections have been conducted in the Dakotas (Stewart and Kantrud, 1972; Brewster et al., 1976) and Oklahoma (Heitmeyer, 1980).

All wetland classification occurred during two-week survey periods in 1992-93. Surveys were conducted 19 September to 3 October, 21 November to 5 December, 2 to 16 January, and 20 March to 3 April.

All quarter-sections were visited once per survey period. Surveys did not include national wildlife refuge lands with large expanses of coastal marsh, large bays, the Laguna Madre, or island habitats because ground surveys were impractical and wetland areas were better documented on these public lands.

All wetlands and deep-water habitats observed on quarter-sections were classified according to Cowardin et al. (1979), but seasonally flooded basins or flats (e.g., sheet-water on cropland or pastures) were also incorporated (Martin et al., 1953) into the classification system. Both wetlands and deep-water habitats were considered to be wetlands for classification and discussion purposes. System, subsystem, class, and subclass were recorded for each wetland. Wetlands were classified during each survey period.

Wetland size was determined following methods of Millar (1973). To distinguish between organic and mud subclasses we determined if soil was organic in the field. Soil was considered to be organic if the top 5 cm under the litter layer was estimated to contain at least 1/6 (by volume) rubbed fiber (Soil Conservation Service, 1975).

Special modifiers were recorded and placed into one of three categories: farmed, manmade, and natural. Wetlands were considered natural if no earth-work had been conducted in them. Wetlands that had fences in them or cattle grazing on them were considered natural. Wetlands were considered manmade if they had any of the following Cowardin et al. (1979) modifiers: excavated, impounded, diked, or artificial.

Seasonal estimates of wetlands were calculated using SAS (SAS, 1988). Mean area of each wetland type within sample quarter-sections in each stratum were multiplied by the area of each stratum, and the totals were added to give study area estimates. Standard errors associated with estimates of wetlands were calculated following procedures for weighted pooled stratified random samples (Kish, 1965).

RESULTS AND DISCUSSION

We classified 77 subclasses of wetlands in the study area. We estimated 125,187 wetlands in January 1993 (Table 1). Palustrine and lacustrine wetlands were also most abundant in January at 95,628 and 4,687, respectively. Estuarine wetland numbers peaked in September 1992 at 13,289 and riverine wetlands in November at 16,471.

Total wetland area (area of surface water) peaked in September 1992 at 484,760 ha (Table 2). Estuarine and palustrine wetland area also peaked in September at 145,768 ha and 249,291 ha, respectively. Lacustrine wetland area was highest in January 1993 (97,079 ha) and riverine area was highest in November 1992 (12,689 ha).

Wetland estimates derived from Landsat imagery (Gilmer et al., 1988) or aerial photographs (Cowardin et al. 1981) are often subject to error. Small wetlands ($\leq$0.5 ha) and those obscured by dense forest or brush cover may not be visible on aerial photographs (Leibowitz et al., 1991). Additionally, a wetland may be misclassified, sites identified as wetlands may be non-wetlands, and others may be overlooked. Wetlands are sufficiently dynamic that a 1-time survey often result in an improper classification. In general, these errors were not problems for our ground surveys. Our information provides a valuable data base for evaluating and implementing wetland management strategies in this region.

Table 1. Total estimated numbers and standard errors (SE)† of wetlands in the Texas Mid-coast and Laguna Madre initiative areas of coastal Texas during September and November 1992 and January and March 1993 quarter-section surveys.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Estuarine	13,289	1,565	11,820	1,465	11,661	1,514	11,010	1,427
Intertidal	8,005	1,124	6,493	983	6,345	1,065	5,815	934
Aquatic-bed	1,794	463	1,794	464	1,096	388	897	368
Algal	371	143	371	143	142	62	173	71
Manmade	52	52	52	52	52	52	52	52
Rooted vascular	1,423	408	1,423	408	989	383	725	361
Manmade	0	0	0	0	0	0	118	118
Emergent	3,322	514	2,741	460	2,395	510	2,103	409
Nonpersistent	201	94	121	56	0	0	118	118
Persistent	3,121	505	2,117	394	2,394	510	1,985	392
Manmade	452	218	504	223	366	189	228	105
Reef	40	28	40	28	60	35	40	28
Mollusk	40	28	40	28	60	35	40	28
Rocky shore	20	20	40	28	40	28	20	20
Rubble	20	20	40	28	40	28	20	20
Manmade	20	20	40	28	40	28	20	20
Scrub-shrub	233	79	112	62	52	52	112	112
Broad-leaved	141	53	20	20	52	52	112	69
Needle-leaved	92	59	92	56	0	0	0	0
Streambed	535	258	80	49	337	202	219	162
Mud	515	257	80	49	337	202	219	162
Manmade	178	126	60	45	60	45	198	161
Organic	20	20	0	0	0	0	0	0

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Unconsolidated shore	2,061	572	1,685	509	2,366	578	2,423	543
Cobble-gravel	331	331	331	331	371	332	351	331
Mud	1,226	459	1,030	383	1,570	467	1,547	423
Manmade	391	332	411	333	569	369	411	333
Organic	141	60	100	53	221	71	241	74
Manmade	40	40	40	40	20	20	20	40
Sand	345	86	224	72	204	70	284	85
Manmade	60	45	60	45	60	45	60	45
Subtidal	5,284	864	5,327	865	5,316	854	5,195	857
Aquatic-bed	771	157	711	154	524	123	518	130
Algal	176	92	124	76	72	55	144	78
Manmade	104	73	104	73	52	52	103	73
Floating vascular	0	0	0	0	52	52	0	0
Manmade	0	0	0	0	52	52	0	0
Rooted vascular	595	128	587	134	400	98	374	104
Manmade	75	57	75	57	43	31	75	57
Reef	20	20	20	20	20	20	20	20
Mollusk	20	20	20	20	20	20	20	20
Rock bottom	43	31	23	23	23	23	23	23
Bedrock	23	23	23	23	23	23	23	23
Rubble	20	20	0	0	0	0	0	0
Manmade	20	20	0	0	0	0	0	0
Unconsolidated bottom	4,449	849	4,573	851	4,697	844	4,634	846
Cobble-gravel	23	23	23	23	46	33	230	23

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Mud	4,326	848	4,398	849	4,458	840	4,438	844
Manmade	2,217	380	2,313	37724	2,177	357	2,073	352
Organic	40	28	92	59	164	81	112	62
Manmade	0	0	52	52	104	73	52	52
Sand	60	35	60	35	80	40	60	35
Lacustrine	3,775	1,216	4,538	1,254	4,687	1,282	4,189	1,256
Limnetic	1,047	566	1,047	566	1,047	566	1,047	566
Rock bottom	158	158	158	158	158	158	158	158
Rubble	158	158	158	158	158	158	158	158
Manmade	158	158	158	158	158	158	158	158
Unconsolidated bottom	889	544	889	544	889	544	889	544
Mud	889	544	889	544	889	544	889	544
Manmade	889	544	889	544	889	544	889	544
Littoral	2,728	760	3,491	821	3,640	834	3,142	792
Aquatic-bed	949	358	791	322	336	200	495	255
Algal	0	0	0	0	0	0	158	158
Floating vascular	751	321	573	279	158	158	276	197
Manmade	40	28	20	20	0	0	0	0
Rooted vascular	198	161	218	161	178	123	60	35
Manmade	198	161	218	161	40	28	60	35
Emergent	0	0	0	0	118	118	118	118
Nonpersistent	0	0	0	0	118	118	118	118
Rock bottom	495	475	495	475	495	475	495	475
Bedrock	475	475	475	475	475	475	475	475

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Manmade	475	475	475	475	475	475	475	475
Rubble	20	20	20	20	20	20	20	20
Manmade	20	20	20	20	20	20	20	20
Rocky shore	0	0	0	0	158	158	158	158
Rubble	0	0	0	0	158	158	158	158
Unconsolidated bottom	772	310	990	351	1,485	443	1,209	385
Cobble-gravel	222	139	222	139	222	139	222	139
Manmade	222	139	222	139	222	139	222	139
Mud	432	191	650	251	1,145	370	869	298
Manmade	222	139	380	186	737	290	619	246
Sand	118	118	118	118	118	118	118	118
Manmade	118	118	118	118	118	118	118	118
Unconsolidated shore	512	367	1,214	484	1,047	458	667	399
Mud	0	0	0	0	331	331	20	20
Organic	512	367	1,214	484	716	317	647	399
Farmed	354	331	1,056	459	558	276	647	398
Manmade	158	158	158	158	158	158	0	0
Palustrine	40,893	3,780	64,551	5,238	95,628	9,234	88,353	7,194
Aquatic-bed	4,885	891	4,073	830	3,037	696	4,718	1,257
Algal	1,001	427	843	397	1,015	468	1,636	578
Manmade	553	244	394	186	567	261	799	478
Floating vascular	1,970	671	1,771	653	869	430	2,014	936
Manmade	1,303	504	967	499	552	368	1,519	777

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Rooted vascular	1,913	430	1,458	350	1,153	299	1,067	300
Manmade	1,464	376	1,128	318	782	259	817	266
Emergent	14,615	1,747	17,695	1,902	18,091	1,863	25,596	2,528
Nonpersistent	1,542	576	2,039	664	3,619	913	6,469	1,041
Farmed	0	0	0	0	0	0	316	222
Manmade	1,108	470	1,188	415	2,353	677	4,689	911
Persistent	13,073	1,592	15,655	1,715	14,472	1,529	19,127	2,133
Farmed	5,997	1,087	4,136	783	2,891	672	2,928	961
Manmade	4,003	717	4,849	794	5,346	843	8,617	1,233
Forested	434	253	1,424	557	1,286	486	1,502	568
Broad-leaved deciduous	434	253	1,404	556	1,266	159	1,502	568
Manmade	158	158	475	273	178	159	751	404
Dead	0	0	20	20	20	20	0	0
Manmade	0	0	20	20	20	20	0	0
Rock bottom	0	0	20	20	20	20	20	20
Bedrock	0	0	20	20	20	20	20	20
Manmade	0	0	20	20	20	20	20	20
Scrub-shrub	3,484	1,075	5,027	1,359	4,912	1,255	6,368	1,311
Broad-leaved deciduous	3,172	1,057	4,710	1,346	4,734	1,249	6,011	1,258
Manmade	705	503	1,234	622	1,200	474	2,063	586
Broad-leaved evergreen	0	0	0	0	0	0	158	158
Dead	138	121	158	121	158	121	158	121
Needle-leaved evergreen	158	158	158	158	20	20	40	28
Manmade	158	158	158	158	20	20	40	28

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Unconsolidated bottom	12,256	2,065	13,984	2,185	15,029	2,355	12,748	2,020
Cobble-gravel	262	174	262	174	420	325	443	326
Manmade	262	174	28	28	420	325	443	326
Mud	10,102	1,865	11,790	2,035	12,231	2,121	10,361	1,793
Manmade	7,415	1,471	8,871	1,660	9,312	1,723	7,617	1,317
Organic	822	336	1,198	419	1,645	531	1,092	392
Farmed	0	0	0	0	118	118	0	0
Manmade	591	264	968	364	965	340	861	332
Sand	1,070	447	733	318	733	318	851	353
Manmade	1,010	446	693	316	693	316	831	352
Unconsolidated shore	5,215	1,313	22,328	2,581	53,253	8,108	31,403	5,386
Cobble-gravel	80	63	0	0	0	0	0	0
Manmade	80	63	0	0	0	0	0	0
Mud	2,197	860	4,337	1,225	7,927	3,633	3,664	1,027
Farmed	52	52	158	158	158	158	158	158
Manmade	615	292	1,723	667	5,986	3,544	2,198	678
Organic	1,115	635	15,031	2,073	43,530	6,154	29,101	5,008
Farmed	677	592	13,780	1,965	36,207	4,967	24,905	4,173
Manmade	60	60	555	277	5,877	3,614	4,018	2,883
Sand	316	199	198	125	259	138	515	257
Manmade	178	160	40	28	80	63	219	164
Vegetated	1,507	514	2,762	742	1,536	732	4,123	1,145
Farmed	0	0	0	0	23	23	0	0
Manmade	820	326	411	231	223	168	1,200	485

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Riverine	9,577	1,134	16,471	1,463	13,211	1,282	11,508	1,195
Intermittent	3,426	753	9,264	1,215	6,331	982	4,508	844
Streambed	3,426	753	9,624	1,215	6,331	982	4,508	844
Bedrock	20	20	0	0	0	0	0	0
Mud	2,790	670	7,017	1,069	5,005	847	3,875	799
Manmade	2,295	577	5,751	996	3,878	764	2,946	2,108
Organic	279	166	909	342	296	198	434	253
Manmade	239	163	731	302	296	198	434	253
Sand	20	20	377	226	397	227	178	159
Manmade	20	20	178	159	178	159	20	20
Vegetated	316	223	1,321	440	633	386	20	20
Manmade	316	223	1,163	823	633	386	20	20
Lower perennial	5,419	821	5,916	864	6,126	877	5,988	865
Aquatic-bed	595	262	397	205	198	128	357	203
Algal	0	0	0	0	20	20	20	20
Manmade	0	0	0	0	20	20	20	20
Floating vascular	475	256	337	202	158	125	158	125
Manmade	475	256	337	202	158	125	158	125
Rooted vascular	121	56	60	35	20	20	20	20
Manmade	80	40	20	20	20	20	20	20
Emergent	158	158	0	0	0	0	158	158
Nonpersistent	158	158	0	0	0	0	158	158
Manmade	0	0	0	0	0	0	158	158
Unconsolidated bottom	4,665	769	5,519	842	5,927	868	5,473	832

Table 1. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Cobble-gravel	0	0	118	118	118	118	118	118
Manmade	0	0	118	118	118	118	118	118
Mud	3,999	716	4,938	802	5,346	830	4,891	791
Manmade	2,641	593	3,170	663	3,420	683	3,262	666
Organic	507	224	305	177	305	177	305	177
Manmade	326	157	124	76	124	76	124	76
Sand	158	158	158	158	158	158	158	158
Tidal	575	357	773	307	595	280	854	324
Unconsolidated bottom	417	229	733	303	417	229	676	281
Mud	417	229	615	279	417	229	676	281
Manmade	178	159	198	160	178	159	240	163
Organic	0	0	118	118	0	0	0	0
Manmade	0	0	118	118	0	0	0	0
Unconsolidated shore	158	158	40	28	178	160	178	160
Mud	158	158	40	28	20	20	20	20
Manmade	158	158	0	0	20	20	20	20
Organic	0	0	0	0	158	158	158	158
Upper perennial	158	158	158	158	158	158	158	158
Unconsolidated bottom	158	158	158	158	158	158	158	158
Cobble-gravel	158	158	158	158	158	158	158	158
Totals	67,534	4,759	97,380	6,246	125,187	9,789	115,060	7,828

†SE was derived from variance estimates calculated following procedures for weighted pooled stratified random samples from Kish (1965).

Table 2. Total estimated hectares and standard errors (SE)† of wetlands in the Texas Mid-coast and Laguna Madre initiative areas of coastal Texas during September and November 1992 and January and March 1993 quarter-section surveys.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Estuarine	145,768	13,597	112,089	11,485	98,542	11,077	105,070	11,521
Intertidal	106,695	12,664	74,354	10,441	61,192	10,101	68,753	10,544
Aquatic-bed	31,461	8,270	27,895	7,952	20,356	7,673	15,130	6,829
Algal	4,957	1,809	3,408	1,185	1,067	759	2,967	2,879
Manmade	11	11	11	11	11	11	11	11
Rooted vascular	26,504	7,985	24,487	7,805	19,289	7,640	12,163	6,078
Manmade	0	0	0	0	0	0	13	13
Emergent	50,828	5,606	32,692	4,408	17,697	3,135	23,227	3,710
Nonpersistent	1,970	790	1,420	917	0	0	875	875
Persistent	48,858	5,528	31,272	4,326	17,697	3,135	22,352	3,606
Manmade	278	164	258	143	91	44	201	141
Reef	67	58	67	58	97	64	83	61
Mollusk	67	58	67	58	97	64	83	61
Rocky shore	144	144	71	69	220	166	94	94
Rubble	144	144	68	68	68	68	94	94
Manmade	144	144	68	68	68	68	94	94
Scrub-shrub	2,983	1,296	166	108	6	6	365	280
Broad-leaved deciduous	2,822	1,290	91	91	6	6	365	280
Needle-leaved evergreen	161	145	75	59	0	0	0	0
Streambed	87	42	15	9	43	24	68	42
Mud	86	42	15	9	43	24	68	42
Manmade	35	24	11	7	12	9	36	27
Organic	1	1	0	0	0	0	0	0

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Unconsolidated shore	21,125	6,770	13,448	4,720	22,772	5,340	29,786	6,408
Cobble-gravel	4,402	4,267	4,265	4,265	4,371	4,265	4,316	4,265
Mud	10,774	4,957	6,588	1,818	12,445	2,673	16,799	4,201
Manmade	467	313	1,106	634	991	525	947	667
Organic	2,978	1,434	1,120	690	4,171	1,665	6,339	2,197
Manmade	696	696	177	177	58	58	338	338
Sand	2,971	1,132	1,476	653	1,785	820	2,332	1,076
Manmade	0	0	74	52	74	52	74	52
Subtidal	39,074	4,775	37,735	4,712	37,349	4,676	36,318	4,637
Aquatic-bed	12,173	2,780	11,081	2,659	9,875	2,574	9,105	2,601
Algal	1,401	982	591	556	591	591	944	645
Manmade	36	25	36	25	19	19	36	25
Floating vascular	0	0	0	0	4	4	0	0
Manmade	0	0	0	0	4	4	0	0
Rooted vascular	10,773	2,608	10,490	2,607	9,279	2,519	8,161	2,527
Manmade	14	11	14	11	556	546	14	11
Reef	18	18	18	18	18	18	18	18
Mollusk	18	18	18	18	18	18	18	18
Rock bottom	1,146	811	600	600	600	600	600	600
Bedrock	600	600	600	600	600	600	600	600
Rubble	546	546	0	0	0	0	0	0
Manmade	546	546	0	0	0	0	0	0
Unconsolidated bottom	25,736	3,865	26,036	3,888	26,850	3,891	26,595	3,862
Cobble-gravel	450	450	450	450	1,049	747	450	450

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Mud	24,003	3,796	24,202	3,819	23,612	3,744	24,273	3,767
Manmade	7,689	2,035	8,348	2,124	5,764	1,690	4,819	1,427
Organic	390	310	480	323	989	588	977	592
Manmade	0	0	90	90	107	92	90	90
Sand	894	627	894	627	1,200	696	894	627
Lacustrine	80,262	19,743	95,046	20,982	97,079	21,113	87,930	20,283
Limnetic	23,264	11,576	23,264	11,576	23,264	11,576	23,264	11,576
Rock bottom	7,537	7,537	7,537	7,537	7,537	7,537	7,537	7,537
Rubble	7,537	7,537	7,537	7,537	7,537	7,537	7,537	7,537
Manmade	7,537	7,537	7,537	7,537	7,537	7,537	7,537	7,537
Unconsolidated bottom	15,727	8,812	15,727	8,812	15,730	8,812	15,727	8,812
Mud	15,727	8,812	15,727	8,812	15,730	8,813	15,727	8,812
Manmade	15,727	8,812	15,727	8,812	15,730	8,813	15,727	8,812
Littoral	56,998	15,269	71,782	16,888	73,812	16,952	64,666	15,814
Aquatic-bed	27,459	11,870	22,913	11,501	9,951	7,834	11,171	6,586
Algal	0	0	0	0	0	0	3,406	3,406
Floating vascular	20,147	10,173	14,365	8,614	7,691	7,691	6,848	5,626
Manmade	1,250	975	917	917	0	0	0	0
Rooted vascular	7,312	6,185	8,548	7,667	2,260	1,491	917	538
Manmade	7,312	6,185	8,548	7,667	694	490	917	538
Emergent	0	0	0	0	953	953	953	953
Nonpersistent	0	0	0	0	953	953	953	953
Rock bottom	703	648	703	648	703	648	703	648
Bedrock	646	646	646	646	646	646	646	646

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Manmade	646	646	646	646	646	646	646	646
Rubble	58	58	58	58	58	58	58	58
Manmade	58	58	58	58	58	58	58	58
Rocky shore	0	0	0	0	357	357	357	357
Rubble	0	0	0	0	357	357	357	357
Unconsolidated bottom	22,164	8,010	28,842	9,731	45,270	12,997	38,366	12,260
Cobble-gravel	6,224	3,933	6,224	3,933	6,224	3,933	6,224	3,933
Manmade	6,224	3,933	6,224	3,933	6,224	3,933	6,224	3,933
Mud	14,758	6,530	21,463	8,514	37,864	12,121	30,961	11,349
Manmade	10,429	6,019	13,069	6,421	26,924	10,273	21,185	8,272
Sand	1,181	1,181	1,181	1,181	1,181	1,181	1,181	1,181
Manmade	1,181	1,181	1,181	1,181	1,181	1,181	1,181	1,181
Unconsolidated shore	6,672	5,341	19,325	7,867	16,708	7,765	13,117	7,614
Mud	0	0	0	0	5,174	5,174	238	238
Organic	6,672	5,341	19,325	7,869	11,534	5,790	12,879	7,610
Farmed	5,360	5,177	18,012	7,765	10,,221	5,648	12,879	1,125
Manmade	1,312	1,312	1,312	1,312	1,313	1,313	0	0
Palustrine	249,291	37,601	158,928	25,310	142,324	20,347	127,046	16,209
Aquatic-bed	5,082	1,307	4,180	1,252	2,669	774	4,644	1,692
Algal	213	80	156	57	194	78	476	236
Manmade	184	76	127	51	164	73	420	234
Floating vascular	1,330	806	1,732	1,006	289	203	2,102	1,326
Manmade	1,020	781	1,443	987	19	10	1,823	1,305

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Rooted vascular	3,539	1,035	2,292	748	2,186	745	2,066	730
Manmade	2,844	967	1,610	663	1,570	664	1,657	670
Emergent	217,176	36,084	106,681	21,272	95,501	19,756	79,775	14,621
Nonpersistent	1,726	1,149	1,366	572	3,174	1,440	5,631	3,030
Farmed	0	0	0	0	0	0	2,894	2,810
Manmade	1,228	1,097	593	390	2,306	1,350	1,710	1,062
Persistent	217,176	37,778	106,681	21,272	92,317	19,730	74,144	14,367
Farmed	48,580	5,525	73,107	19,321	57,733	18,082	21,099	8,958
Manmade	15,280	6,640	14,428	5,461	13,500	5,501	16,391	5,627
Forested	6,756	4,778	16,788	10,960	5,668	3,629	7,453	4,116
Broad-leaved deciduous	6,756	4,778	16,785	10,960	5,665	3,629	7,453	4,116
Manmade	22	22	10,108	10,053	32	29	3,335	2,538
Dead	0	0	3	3	3	3	0	0
Manmade	0	0	3	3	3	3	0	0
Rock bottom	0	0	1	1	1	1	2	2
Bedrock	0	0	1	1	1	1	2	2
Manmade	0	0	1	1	1	1	2	2
Scrub-shrub	8,057	5,671	7,765	4,952	3,696	1,085	5,762	1,355
Broad-leaved deciduous	2,420	958	2,860	997	3,574	1,083	5,207	1,306
Manmade	328	238	1,469	640	394	167	736	377
Broad-leaved evergreen	0	0	0	0	0	0	11	11
Dead	46	37	51	39	64	44	64	44
Needle-leaved evergreen	5,591	5,591	4,854	4,854	58	58	480	368
Manmade	5,591	5,591	4,854	4,854	58	58	480	368

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Unconsolidated bottom	8,917	2,165	9,472	2,183	93	85	102	86
Cobble-gravel	50	43	50	43	93	85	102	86
Manmade	50	43	50	43	91	44	102	86
Mud	6,098	1,502	6,439	1,509	7,820	2,082	5,437	1,196
Manmade	5,207	1,457	5,753	1,488	7,129	2,067	4,784	1,170
Organic	1,568	1,054	1,836	1,076	2,174	1,127	1,784	1,075
Farmed	0	0	0	0	338	338	0	0
Manmade	1,414	1,047	1,683	1,069	1,678	1,068	1,630	1,068
Sand	1,202	706	1,146	703	1,167	704	1,147	703
Manmade	1,099	702	1,049	699	1,049	699	1,071	699
Unconsolidated shore	1,576	383	12,674	2,309	23,534	3,434	20,941	3,385
Cobble-gravel	7	5	0	0	0	0	0	0
Manmade	7	5	0	0	0	0	0	0
Mud	389	163	1,577	699	1,234	435	2,682	1,212
Farmed	15	15	28	28	28	28	2	2
Manmade	206	121	937	636	797	371	2,336	1,191
Organic	664	268	9,493	1,943	21,913	3,411	16,017	2,879
Farmed	236	148	9,127	1,941	20,891	3,389	15,710	2,879
Manmade	282	170	113	69	431	211	280	182
Sand	62	34	74	47	122	72	168	103
Manmade	41	31	45	43	29	27	53	38
Vegetated	453	187	1,531	790	265	122	2,073	1,060
Farmed	0	0	0	0	52	52	0	0
Manmade	280	152	33	20	45	33	164	76

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Riverine	9,439	2,399	12,689	2,704	12,202	2,559	10,551	2,247
Intermittent	281	67	2,788	1,527	2,986	1,439	519	119
Streambed	281	67	2,788	1,527	2,968	1,439	519	119
Bedrock	3	3	0	0	0	0	0	0
Mud	214	55	2,306	1,516	2,602	1,414	473	117
Manmade	193	54	720	208	911	336	410	113
Organic	38	23	123	47	28	19	29	20
Manmade	35	22	110	45	28	19	29	20
Sand	1	1	82	70	305	274	16	15
Manmade	1	1	70	70	273	272	1	1
Vegetated	25	22	106	106	50	30	1	1
Manmade	25	22	106	106	50	30	1	1
Lower perennial	6,413	1,579	6,445	1,574	6,566	1,575	6,541	1,575
Aquatic-bed	424	282	146	83	95	73	119	77
Algal	0	0	0	0	8	8	32	29
Manmade	0	0	0	0	8	8	4	4
Floating vascular	390	282	132	83	82	72	82	72
Manmade	390	282	132	83	82	72	82	72
Rooted vascular	33	16	14	8	5	5	5	5
Manmade	24	24	4	4	5	5	5	5
Emergent	42	42	0	0	0	0	63	63
Nonpersistent	42	42	0	0	0	0	63	63
Manmade	0	0	0	0	0	0	63	63
Unconsolidated bottom	5,947	1,554	6,299	2,004	6,972	1,573	6,359	1,572

Table 2. Continued.

System Subsystem Class Subclass Special modifiers	Sep		Nov		Jan		Mar	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Cobble-gravel	0	0	201	201	201	201	201	201
Manmade	0	0	201	201	201	201	201	201
Mud	5,509	1,533	5,957	1,558	6,130	1,966	6,018	1,558
Manmade	2,836	984	2,653	874	2,829	878	2,757	876
Organic	388	226	91	48	91	48	91	48
Manmade	343	222	44	31	45	29	45	29
Sand	50	50	50	50	50	50	50	50
Tidal	1,936	1,629	2,648	1,400	1,841	1,207	2,863	1,398
Unconsolidated bottom	1,398	1,098	2,643	1,400	1,812	1,207	2,654	1,397
Mud	1,398	1,098	2,632	1,400	1,812	1,207	2,654	1,397
Manmade	1,084	1,078	1,788	1,288	1,084	1,078	1,855	1,289
Organic	0	0	11	11	0	0	0	0
Manmade	0	0	11	11	0	0	0	0
Unconsolidated shore	538	538	4	4	29	29	29	29
Mud	538	538	4	4	1	1	1	1
Manmade	538	538	0	0	1	1	1	1
Organic	0	0	0	0	28	28	28	28
Upper perennial	809	809	809	809	809	809	809	809
Unconsolidated bottom	809	809	809	809	809	809	809	809
Cobble-gravel	809	809	809	809	809	809	809	809
Totals	484,760	45,804	378,752	36,724	350,147	34,521	330,597	30,906

†SE was derived from variance estimates calculated following procedures for weighted pooled stratified random samples from Kish (1965).

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A Comparison of Herpetofauna Detection and Capture Techniques in Southern New Mexico

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ABSTRACT

We conducted systematic trials of four herpetofauna survey methods to assess their effectiveness in the Chihuahuan desert. Drift fences with pitfall and funnel traps, pitfall traps without fences, artificial habitats (with and without water added), and line transects were paired in arroyos and adjacent uplands. Times taken to set up, maintain, and remove survey materials were recorded. Twenty-seven captures or detections of six species were recorded. While the unwatered artificial habitats were most efficient in capture rate for all species pooled, the distribution of the species captured indicated that to give representative results, surveys should incorporate a combination of techniques. More extensive trials would be useful in confirming these results and assessing seasonal effects.

KEYWORDS: survey, inventory, monitoring, community

A number of techniques have been developed for surveying herpetofaunal communities (Campbell and Christman, 1982; Vogt and Hine, 1982; Jones, 1988; Szaro et al., 1988). These include pitfall traps with and without drift fences and funnel traps (Gibbons and Semlitsch, 1981; Bury and Corn, 1988), time-constrained transect or quadrat searches (Campbell and Christman, 1982; Bury and Corn, 1988; Jones, 1988; Raphael, 1988), artificial habitats (e.g. DeGraaf and Yamasaki, 1992; Fitch, 1992), glue traps (Bauer and Sadlier, 1992), road searches (Jones, 1988; Dodd et al., 1989), and incidental observations (Campbell and Christman, 1982). With the exception of pitfall and drift fence design (Gibbons and Semlitsch, 1981; Campbell and Christman, 1982; Vogt and Hine, 1982; Bury and Corn, 1987), comparisons of these techniques remain largely anecdotal (Jones, 1986). As part of an assessment of herpetofaunal community structure in the upper Chihuahuan desert ecotype, we investigated the effectiveness and efficiency of four capture/detection techniques.

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MATERIALS AND METHODS

We conducted four systematic trials of the four techniques in the McGregor Range section of Fort Bliss in southern New Mexico. The trials were run in scrub/shrub, montane desert ecotone at about 1,500 m elevation. The dominant shrubs were Apache plume (*Fallugia paradoxa*), salt bush (*Atriplex canescens*), and creosote (*Larrea tridentada*). For each trial, paired trap arrays and transects were placed in an arroyo and in an adjacent upland habitat. Upland sites were 50 m from the corresponding arroyo sites. Drift fence arrays were perpendicular to the arroyo (Szaro and Belfit, 1986) and consisted of two consecutive 7.5 m fences 40 cm high with 11-liter (22 cm diameter by 31 cm deep) pitfall buckets at the center and at each end. Funnel traps (Imler, 1945; Fitch, 1987) were placed on both sides midway along each fence. Two sets of artificial habitat arrays (Fitch, 1987) were placed at each site. These consisted of four 37 by 75 cm sheets of 1.3 cm thick plywood elevated by a 8 cm block under each corner and laid out at the corners of a 10 m square. For one of these arrays at each site, 0.5 liter of water was poured slowly on the ground under the center of each plywood sheet daily. Pitfall arrays consisted of four 11-liter buckets arranged in a 10 m square. The buckets were covered by square boards overhanging them by 10 cm and elevated by 8 cm blocks. Two 300 m line transects were established for each trial and habitat. These were walked at 10 m min^{-1} (Werschkul, 1982). Running down and along the arroyo, each set of capture/detection techniques was laid at 50 m intervals in the following order: first transect; drift fence; watered artificial habitat; unwatered artificial habitat; pitfall traps; and second transect. All surveys were performed by the same individual. During setup (construction), maintenance, processing, and removal for each array or transect, the time taken for the task was noted to the nearest 5 min. While surveying the traps and transects, herpetofauna that were observed incidentally were noted, as were those seen in the general area (within 30 km). The four trials were run from 19 September - 13 October 1992 for a total of 19 days (4, 4, 5, and 6 days, respectively).

RESULTS AND DISCUSSION

Six or 7 species (1 amphibian, 5-6 reptiles) were caught or detected. Some *Cnemidophorus* could be identified to genus only. These were discussed below as a distinct species. Capture/detections included 1 amphibian and 5 or 6 lizard species. All lizards were observed at the study sites or in nearby areas (Table 1). An additional 3 lizards, 3 snakes, and 2 turtle species were observed but not captured or detected.

The total of 27 herpetofauna captures (or detections) was insufficient for statistical comparisons (Table 2), but inspection of the results gives insight into the effectiveness of these techniques: (1) None of the 4 *Cophosaurus texanus* encountered were found under the artificial habitats; (2) *Sceloporus undulatus* was frequently found under unwatered artificial habitats; (3) Pitfall arrays (without drift fences) were ineffective for all species; (4) All of the *Phrynosoma cornutum* and most of the *S. undulatus* were detected by visual means (artificial habitats and line transects).

Generally speaking, the artificial habitats took the least time to set up and process, and line transects the most (Table 3). While the importance of differences in setup, processing, and removal times will vary for other trapping durations, the unwatered artificial habitats were most efficient in captures or detections per hour (Fig. 1); the watered artificial habitats, line transects, and drift fences were intermediate in efficiency, and the pitfall arrays were the least efficient.

Table 1. Herpetofauna captured and detected during the study, observed at the study sites, or observed in the general area during the study period.

Scientific name	English name	Captured and/or Detected	Observed at study sites	Observed in area
Bufo punctatus	Red-spotted toad	X		
Cnemidophorus sp.	Whiptail lizard	X	X	X
Cnemidophorus tesselatus	Checkered whiptail	X	X	X
Cophosaurus texanus	Greater earless lizard	X	X	X
Phrynosoma cornutum	Texas horned lizard	X	X	X
Sceloporus undulatus	Southern prairie lizard	X	X	X
Uta stansburiana	Side-blotched lizard	X		
Phrynosoma modestum	Round-tailed horned lizard		X	X
Sceloporus magister	Twin-spotted lizard		X	
Urosaurus ornatus	Tree lizard			X
Bogertophis subocularis	Trans-Pecos rat snake			X
Crotalus viridis	Prairie rattlesnake			X
Masticophis flagellum	Coachwhip snake			X
Terrapene carolina	Three-toed box turtle			X
Terrapene ornata	Desert box turtle			X

There was fairly close agreement between lizard species captured, observed at the sites, and observed in the area, indicating that lizards were inventoried reasonably well when all techniques were used. No single technique detected all species or performed noticeably better in species richness (Table 2). Although no snakes or box turtles were observed at the sites themselves (Table 1), their presence in the area contrasts markedly with the trapping record. Snakes presumably could have been caught in the funnel traps of the drift fence arrays or detected during line transects. Possibly more intensive sampling would be required to record these species. Box turtles might successfully avoid pitfall traps (even when combined with drift fences) and very extensive sampling would probably be required to record these species in line transects.

Table 2. Number of captures or detections for each species of herpetofauna by technique, southern New Mexico, September and October 1992.

	Artificial Habitat			Line Transect	Drift Fence	Pitfall Array	Total
Species	Watered	Unwatered	Total				
Bufo punctatus	.	.	.	.	2	.	2
Cnemidophorus sp.	1	2	3	2	.	.	5
Cnemidophorus tesselatus	1	1	2	1	1	.	4
Cophosaurus texanus	.	.	.	3	1	.	4
Phrynosoma cornutum	1	1	2	.	.	.	2
Sceloporus undulatus	.	5	5	2	.	1	8
Uta stansburiana	1	.	1	.	1	.	2
Total	4	9	13	8	5	1	27

Because species responded differentially to the various techniques, both in terms of which species were caught and the number of individuals of the species, no single technique can be considered sufficient for assessing lizard communities in the Chihuahuan Desert, at least at these sampling intensities. Combining the data from the unwatered artificial habitat and drift fence arrays accounts for all of the species detected. Notably, three other combinations of two techniques accounted for 6 of the 7 species. A more extensive trial would be useful in determining which technique or combination of techniques would be sufficient for surveying lizards in these habitats.

Other investigations have also concluded that a variety of techniques should be employed in herpetofaunal community inventories. Storm and Pimentel (1954) and Dodd (1991) discussed biases in pitfall/drift fence sampling, while Gibbons and

Semlitsch (1981) indicated that this method is essential for detecting certain species. Campbell and Christman (1982) noted that the relative efficacy of pitfalls and searching varies between habitats. They also showed the importance of night road searches (18 additional species detected) and general collection (25 additional species detected) in compiling species lists. Fitch (1992) noted considerable differences among the susceptibility of various snake species relative to detection technique.

Table 3. Summary of time (in minutes) expended and capture efficiency for herpetofauna capture/detection techniques.

	Artificial Habitat		Line Transect	Drift Fence	Pitfall Array
Activity	Watered	Unwatered			
Setup	145	155	155	395	435
Maintenance	40	15	90	310	230
Processing	420	240	2145	425	345
Removal	80	110	5	130	75
Total	685	520	2395	1260	1085

We expected that in the desert environment, the watered artificial habitat arrays would be a more successful means of detecting herpetofauna than the unwatered arrays. Our data indicate that the opposite may have been true, at least for *S. undulatus*. Two possible reasons for this are that the surveys took place in the fall, rather than during a period of greater heat stress; and that the weather was unseasonably cold during part of the survey period.

When effort was considered, the unwatered artificial habitat array was several times more effective than the other techniques in terms of the number of animals captured or detected (Fig. 1). However, the artificial habitat array and line transect techniques have an important disadvantage in that animals are seldom actually captured. This makes species identification difficult in some cases. Since species identification is a crucial component of community assessment, more than one technique could be employed in a survey protocol. Our trials indicate that for surveying herpetofauna in Chihuahuan Desert habitats, unwatered artificial habitat and drift fence arrays should be combined. Techniques more suitable for snakes and box turtles should also be incorporated if information on these groups is desired.

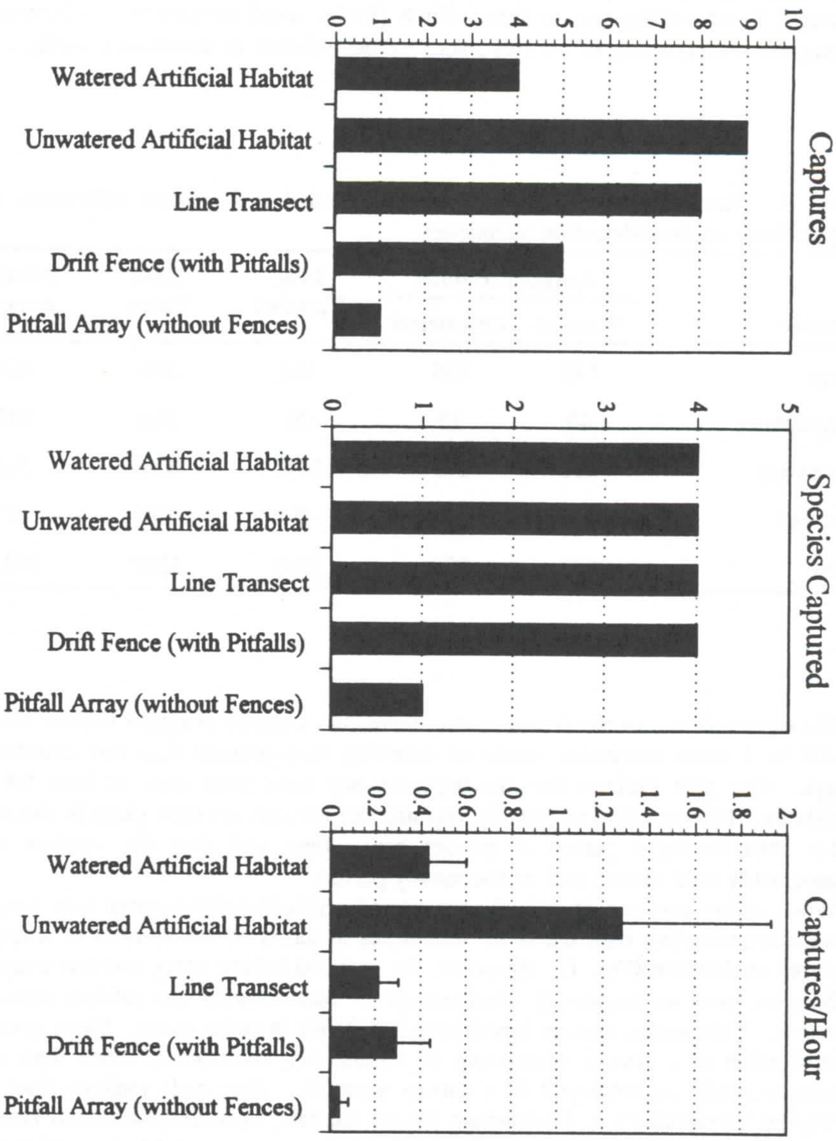

Figure 1. Number of captures or detections, number of species captured or detected, and mean capture or detection rate per hour of effort (± standard error of the mean), for five capture/detection techniques.

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