EFFECTS OF HABITAT MODIFICATION WITH HERBICIDE AND PRESCRIBED BURNING ON SMALL MAMMAL POPULATIONS INHABITING CROSS TIMBERS RANGELAND IN OKLAHOMA

by

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CHAPTER I

INTRODUCTION

This thesis is comprised of 4 manuscripts formatted for submission to the *Journal of Wildlife Management*. This chapter introduces the rest of the thesis. The 4 manuscripts are complete as written and do not require additional support material. The manuscripts include: Chapter II, Effects of herbicide and prescribed burning on white-footed (*Peromyscus leucopus*) populations in central Oklahoma; Chapter III, Responses of eastern woodrat (*Neotoma floridana*) populations to brush management on cross timbers rangeland in Oklahoma; Chapter IV, Populations of cotton rats (*Sigmodon hispidus*) in relation to herbicide and prescribed burning in central Oklahoma; Chapter V, Effect of herbicide and prescribed burning on food habits of eastern woodrats (*Neotoma floridana*) in Oklahoma.

CHAPTER II

EFFECTS OF HERBICIDE AND PRESCRIBED BURNING ON WHITE-FOOTED MOUSE (*PEROMYSCUS LEUCOPUS*) POPULATIONS IN CENTRAL OKLAHOMA

Abstract: I examined the influence of 5 experimental brush treatments on relative population density, reproduction, and condition of white-footed mice (*Peromyscus leucopus*) on cross timbers rangeland in Oklahoma. Experimental treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning, and untreated controls. A total of 1,516 white-footed mice was collected from March 1986 through December 1988. Relative population density varied among seasons and experimental treatments. Highest density occurred in spring and winter 1986 with a decline in 1987 and 1988. Relative population density was highest on herbicide and triclopyr treatments compared to controls and tebuthiuron treatments, spectively. Reproductive activity varied among seasons with peaks in spring and fall. Experimental treatment did not influence reproductive status of females but did influence testes position and spermatogenesis in males. All condition parameters varied among seasons. Body weights and condition scores were highest in fall and stomach content weights were heaviest in summer and fall. Liver and spleen weights were lighest and adrenal glands heaviest in summer. Experimental treatment had no influence on body weight but condition scores were highest for animals on herbicide and burned treatments compared to controls and unburned treatments, respectively. Stomach content weights were heaviest in animals from controls and tebuthiuron treatments compared to herbicide and triclopyr treatments, respectively. Liver and spleen weights from herbicide treatments were heaviest compared to controls and spleen weights were also heaviest on burned treatments. Adrenal gland weights

were lightest on unburned tebuthiuron treatments compared to other herbicide treatments but were not different than controls.

Composition and structure of vegetation are two of the most important determinants of abundance and distribution of small mammal populations (Kaufman and Fleharty 1974, M'Closkey and Lajoie 1975, Barry and Francq 1980, Kaufman et al. 1983). Natural successional and man-induced (usually retrogressional) modifications of the habitat that change these habitat components can be expected to have profound impacts on resident small mammal communities (Keith et al. 1959, Kirkland 1978, Borrecco et al. 1979, Santillo et al. 1989, Lawrence 1966, Buech et al. 77, Kaufman et al. 1988).

The cross timbers ecosystem accounts for nearly 5 million ha of rangeland in Oklahoma, Texas, and Kansas (SCS 1981) and along with other oak-hickery forests of the Ozark Plateaus, represents about 20 million ha of land in the central United States (Garrison et al. 1977). The increased desire of livestock producers to improve brush-dominated rangelands in the Cross Timbers for grazing has led to widespread use of herbicides and prescribed fire. Brush management strategies generally initiate retrogression and are capable of dramatically altering the composition and structure of vegetation (Scifres 1980).

Demographic responses of small mammal communities to the herbicides 2,4-D (Keith et al. 1959), 2,4,5-T (Kirkland 1978), atrazine (Borrecco et al. 1979), and glyphosate (Santillo et al. 1989), as well as, prescribed burning (Lawrence 1966, Kaufman et al. 1988) and wildfires (Cook 1959, Buech et al. 1977) have been examined in a variety of ecosystems. Although herbicides are often followed with prescribed fire treatments to suppress post-treatment resprouting of woody vegetation, few studies (Senzota 1985) have examined the effects of such brush management strategies on small mammal populations.

Two herbicides, tebuthiuron (N-[5-(1,1-dimethyl-ethyl)-1,3,4-thiadiazol-2 yl]-N,N'-dimethylurea) and triclopyr ([(3,5,6-trichloro-2-pyridinyl) oxy] acetic acid), are used for managing the hardwood overstory in the cross timbers vegetation type. Despite increased herbicide use, relatively little is known about wildlife responses to habitat modifications that occur following herbicide application. The primary objectives of my study were to evaluate demographic, reproductive, and condition responses of white-footed mouse Peromyscus leucopus populations to the herbicides tebuthiuron and triclopyr, used in combination with and without annual prescribed burning, in central Oklahoma on oak-dominated cross timbers vegetation. The study area was presentative of typical oak-dominated Cross Timbers rangeland with livestock grazing as the primary agricultural use.

METHODS

Study area.--This study was conducted on the Cross Timbers Experimental Range (CTER), located approximately 11 km southwest of Stillwater, Oklahoma. The CTER encompasses 648 ha of typical Cross Timbers rangeland which is composed of upland forest with interspersed grassland-cedar savannas. The CTER has a long history of cultivation, cropland abandonment, and livestock grazing, which has resulted in a general decline in site potential and range condition (Ewing et al. 1984). Upland forest habitats are dominated by post oak (Quercus stellata) and black-jack oak (Q. marilandica) in the overstory, and eastern redcedar (Juniperus virginiana), rough-leaf dogwood (Cornus drummondii), redbud (Cercis canadensis), American elm (Ulmus americana) and coralberry (Symphoricarpos orbiculatus) in the understory. Understory herbaceous dominants include little bluestem (Schizachyrium scoparium), indiangrass (Sorghastrum nutans), rosette panicgrass (Panicum oligosanthes), and western ragweed (Ambrosia psilostachya).

Experimental Design.--The CTER was divided into 20 fenced 32.4 ha experimental pastures that represent 4 replications of 5 experimental brush treatments in a randomized block design. Pastures were assigned to respective blocks according to their similarity in total woody canopy cover and soils. The 5 experimental treatments included: (1) tebuthiuron, a soil applied herbicide (Elanco Products Co., Division of Eli Lilly and Co., Indianapolis, Indiana 46285), applied aerially at 2.2 kg per ha in March 1983; (2) tebuthiuron (as with treatment #1) with annual prescribed burning beginning April 1985; (3) triclopyr, a foliage applied herbicide (Dow Chemical Co., Midland, Michigan 48674), applied aerially at 2.2 kg per ha in June 1983; (4) triclopyr (as with treatment #3) with annual prescribed burning beginning in April 1985; and (5) untreated control. All experimental pastures were moderately grazed by yearling cattle from April to September of each year.

Animal collection.--White-footed mouse populations were censused seasonally (Mar, Jun, Sep, Dec) in 1986 and 1987 and biannually (Jun and

Dec) in 1988 for a total of 10 sampling periods. For each sampling period, 2 replications of each experimental treatment were censused using removal trapping on a randomly placed 8 x 8 grid (1.1 ha) with 15 m spacing between grid points. Upland forest habitat was censused and trapping grids were relocated before each sampling period so that no area within an experimental pasture was trapped more than once. I also alternated replications censused after every 2 successive sampling periods. Museum Specials (128 each) and Victor Rat Traps (32 each) were evenly distributed on each grid; traps were placed within a 1-m radius of each grid point. A peanut butter and rolled oat mixture and sliced apples were used as bait. Each grid was trapped for 3 consecutive nights with daily removal of all captures and enumeration of all sprung traps. Relative population density was calculated on a catch/unit effort basis and expressed as the number of animals caught/100 trap-nights. A trap-night was defined as 1 snap-trap set for a single 24-hour period. Relative population density was calculated for each treatment replication, and corrections were made for traps sprung by all causes (Nelson and Clark 1973).

Collected animals were returned to the laboratory and total, body, tail, and hindfoot lengths (± 1.0 mm) and body weight (± 0.1 g) measured. Animals ≥ 19.0 g were classified as adults while those ≤ 18.9 g were considered juveniles. Reproductive status of each male was assessed by determining testes position (scrotal, abdominal), epididymal sperm smear score, and weights of the testes and seminal vesicle gland. Presence of spermatozoa in the epididymis was ascertained by cutting the caudal pole, extruding its contents, and smearing across a glass slide. Slides were examined microscopically, and the relative abundance of sperm was assessed by assigning a numerical rank of 0 (none), 1 (trace), 2 (moderate), and 3 (abundant). The condition of the vulva of each female was recorded as perforate or imperforate. Females were classified as pregnant only when embryos were grossly visible upon necropsy. Embryos and uterine scars were enumerated when present. Females were recorded as lactating if mammary tissue was conspicuous with hair-free areas surrounding the nipples. Females were considered reproductively active if pregnant or lactating.

Animal condition was assessed by examining weight ($\pm$0.1 mg) of liver, spleen, adrenal glands, and oven-dry stomach contents in 1986. Contents were removed from each stomach and dried to constant weight at 55 C. A general condition index was calculated for each animal as the proportion of body weight/body length expressed as a percentage.

Statistical Analyses.--Differences in frequency distributions among experimental brush treatments and seasons for age and sex ratios and male (testes position, sperm abundance scores) and female (reproductive status, vulva condition, presence of uterine scars) reproductive parameters were analyzed by chi-square analysis (Koopmans 1981). Relative population density estimates were arcsine transformed (Sokal and Rohlf 1981) and differences among experimental brush treatments and seasons tested by analysis of variance (SAS 1985). Condition (body weight, organ and gland weights, condition score) and morphometric parameters were independently rank transformed prior to data analysis as a method to analyze non-normally distributed data (Conover and Iman 1981). Main and interaction effects of experimental treatment and season were examined by analysis of variance for the rank transformed data (Conover and Iman 1981). Specific contrasts were used in all analysis of variance procedures to compare differences between major treatment components (tebuthiuron vs. triclopyr, burned vs. unburned, brush treated vs. untreated controls).

RESULTS

Population characteristics.--A total of 1,516 white-footed mice was captured over the 3-year study. Relative population densities differed significantly among seasons ($\underline{P} < 0.001$) and experimental brush treatments ($\underline{P} < 0.001$). Although seasonal population trends over the 3-year study were similar, the amplitude of these seasonal fluctuations differed greatly among the 5 experimental treatments (Fig. 1). Differences in relative population density among seasons were most pronounced in 1986, with highest relative densities occurring in spring and winter (Fig. 1). Relative population densities across all experimental brush treatments gradually decreased from a high in 1986 to a low in 1988.

Specific contrasts revealed that relative population densities on herbicide-treated pastures were significantly greater ($\underline{P} < 0.001$) than untreated control pastures. Relative population densities of white-footed mice also were greater ($\underline{P} < 0.030$) on pastures treated with triclopyr than tebuthiuron. Relative population densities approached greater ($\underline{P} < 0.064$) levels on unburned compared to burned experimental pastures. Overall, relative population densities of white-footed mice were greater on unburned triclopyr treated pastures compared to the other 4 treatments during all 3 years of our study.

Juvenile sex ratios did not differ ($\underline{P} > 0.100$) among experimental brush treatments or seasons. A total of 707 juvenile white-footed mice was collected over the 3 year study; males comprised 53.3% of the sample. The percentage of males in the adult population (Fig. 2) differed among seasons in 1986 ($\underline{X}^2 = 16.7$, 3 df, $\underline{P} < 0.001$) and approached significance in 1987 ($\underline{X}^2 = 7.8$, 3 df, $\underline{P} < 0.100$). Percentage of adult males was lowest in fall and highest in winter for 1986 and 1987. The percentage of the adult population comprised of males did not differ ($\underline{P} > 0.100$) among experimental brush treatments.

Recruitment of juveniles occurred in all 10 sampling periods (Fig. 3). Juveniles comprised >30% of our sample for each season except fall 1986 and 1987. Percentage of juveniles in white-footed mouse populations showed a significant ($\underline{X}^2 = 64.9$, 3 df, $\underline{P} < 0.001$) amount of variation among seasons over the 3-year study (Fig. 3). Frequency of occurrence of juveniles in populations was less than expected in fall and greater than expected in summer. Frequency of occurrence of juveniles (all seasons and years pooled) in populations inhabiting herbicide-treated pastures was greater ($\underline{X}^2 = 3.97$, 1 df, $\underline{P} < 0.050$) than untreated controls (Fig. 3). Differences among brush treatments were also apparent in March ($\underline{X}^2 = 10.3$, 1 df, $\underline{P} < 0.005$) 1986 when percentage of juveniles was greater in triclopyr than tebuthiuron pastures.

Reproductive activity.--I may have underestimated the number of reproductively active females because of my inability to detect very early pregnancies. Adult females found to be reproductively active were observed throughout the study, except in spring 1987 and summer 1988 (Fig. 4). However, distinct seasonal peaks of reproductive activity were evident with the highest peak of reproductive activity occuring at the start of the study in spring 1986 where 88% of adult females were reproductively active. Percentage of reproductively active adult males also was high in fall 1986 and 1987. Experimental brush treatments did not influence ($P > 0.100$) the percentage of reproductively active adult females in any season sampled.

Litter size of pregnant females varied from 2 to 8 with an overall mean of 3.77 ± 0.10 (SE) fetuses/pregnant adult female (Table 1). Mean litter size differed significantly among seasons ($P < 0.001$) and experimental brush treatments ($P < 0.020$) in 1986 but not in 1987 or 1988. Mean litter size was greatest in fall ($\bar{X} = 4.61 \pm 0.21$) and lowest in spring ($\bar{X} = 3.47 \pm 0.10$). Specific contrasts were not estimatible due to a lack of pregnant females in tebuthiuron-treated pastures in 9 of the 10 sampling periods. However, multiple range tests indicated that mean litter sizes of pregnant females inhabiting untreated control and triclopyr-treated pastures were greater ($P < 0.050$) than in tebuthiuron-treated pastures subjected to burning.

Condition of the vulva (perforate, imperforate) by itself is not a reliable measure of the number of reproductively active females because the vulva can reseal after copulation and perforate females may not always breed (David and Jarvis 1985). The percentage of adult females with a perforate vulva was correlated (*r* = 0.97, *P* < 0.001) with the percentage of reproductively active adult females within a season. Percentage of adult females with a perforate vulva differed (X^2 = 51.4, 3 df, *P* < 0.001) among seasons being greater than expected in fall 1986 and 1987 than in other seasons (Fig. 5). Percentage of adult females in the population with a perforate vulva also differed (X^2 = 11.6, 4 df, *P* < 0.025) among experimental brush treatments and was greater than expected in populations from unburned triclopyr-treated pastures. Comparisons between burned (19.8%) and unburned (33.1%) treatments revealed a higher than expected frequency of females with a perforate vulva on unburned pastures (X^2 = 4.6, 1 df, *P* < 0.050). Frequency of females in the population with visible uterine scars varied significantly (X^2 = 16.4, 3 df, *P* < 0.001) among seasons, being greater than expected in summer. However, the number of females with visible uterine scars did not differ (*P* > 0.100) among experimental brush treatments and was negatively correlated (*r* = -0.81, *P* < 0.01) to reproductively active females in a season.

Testes position and relative degree of spermatogenesis mirrored the temporal pattern observed for adult females (Fig. 6). The percentage of adult males that were scrotal (X^2 = 57.7, 3 df, *P* < 0.001) and had relative sperm abundance scores $\geq$ 2 (X^2 = 113.7, 3 df, *P* < 0.001) were greater than expected in spring and fall and less than expected in summer and winter. Although the number of adult males trapped during fall sampling periods was low, all were reproductively active.

Reproductive activity of adult males appeared to be influenced by experimental brush treatments in spring and summer (Fig. 6). Data pooled across all 3 summers indicated that the percentage of males with scrotal testes was greater ($\underline{X}^2$ = 6.0, 1 df, $\underline{P}$ < 0.025) than expected for tebuthiuron-treated pastures and less ($\underline{X}^2$ = 4.5, 1 df, $\underline{P}$ < 0.050) than expected for untreated controls when compared to triclopyr-treated and herbicide-treated pastures, respectively. Data pooled across the 2 spring seasons revealed that the percentage of males with a relative sperm abundance score $\geq$ 2 was greater ($\underline{X}^2$ = 5.8, 1 df, $\underline{P}$ < 0.025) than expected on unburned compared to burned experimental treatments. No other differences in reproductive activity of adult males were apparent among experimental treatments.

Mean weights of testes and seminal vesicle glands of adult males were significantly ($\underline{P}$ < 0.001) different among pooled seasons (Table 1) and essentially complemented observed differences in reproductive activity based on testes position and relative degree of spermatogenesis. Mean testes and seminal vesicle gland weights for each season differed from all other seasons and were heaviest in fall and lightest in summer. Although experimental brush treatments had no influence ($\underline{P}$ > 0.100) on mean seminal vesicle gland weights, effect of treatments on mean testes weight approached significance ($\underline{P}$ < 0.067). Multiple range tests indicated that mean testes weights of adult males from untreated controls were lighter than those from unburned herbicide treatments.

Condition.--Body weights and relative condition scores of adult white-footed mice were used as gross indices of body condition (Table 2). Seasonal influences on body weights and relative condition scores were highly significant ($P < 0.001$), being highest in fall and lowest in summer. There were no significant ($P > 0.100$) differences in mean adult body weights among experimental brush treatments. However, relative condition scores for adult white-footed mice were significantly ($P < 0.025$) influenced by experimental brush treatments, and there was a significant ($P < 0.001$) treatment by season interaction. Specific contrasts indicated that mean condition scores in white-footed mouse populations inhabiting herbicide-treated pastures were greater ($P < 0.023$) than those from untreated controls. Also, mean condition scores were greater ($P < 0.036$) for adults on burned than unburned treatments.

Mean weights of stomach contents in adults differed significantly ($P < 0.050$) among seasons and experimental brush treatments, and there was a significant ($P < 0.005$) treatment by season interaction (Table 2). Dried stomach contents weighed more in summer and fall than spring. Specific treatment contrasts showed that mean stomach content weights of adult white-footed mice from populations inhabiting untreated control ($P < 0.005$) and tebuthiuron-treated ($P < 0.028$) pastures were greater than those from herbicide-treated and triclopyr-treated pastures, respectively.

Liver, spleen, and adrenal gland weights of adult white-footed mice were used as relative indicators of stress (Christian 1965). Mean ranked liver, spleen, and adrenal gland weights varied significantly ($P < 0.001$) among seasons (Fig. 7). Liver and spleen weights were lightest and adrenal gland weights were heaviest in summer compared to other seasons. Mean ranked liver ($P < 0.001$) and paired adrenal gland weights differed ($P < 0.007$), and spleen weights tended to differ ($P < 0.084$), among experimental brush treatments. Also, effects of experimental brush treatments on liver and spleen weights were significantly ($P < 0.050$) influenced by season. Specific contrasts showed mean ranked liver ($P < 0.001$) and spleen ($P < 0.017$) weights of adult white-footed mice to be significantly greater on herbicide-treated pastures compared to untreated controls. Spleen weights of adults also were heavier ($P < 0.040$) on burned than unburned experimental treatments. No contrasts were significant ($P > 0.100$) for adrenal gland weights. Multiple range tests showed adrenal gland weights of adults from unburned tebuthiuron pastures were lighter than those from other herbicide treatments, but not different from untreated controls.

DISCUSSION

Selective herbicides such as tebuthiuron and triclopyr generally induce retrogression of the cross timbers toward tallgrass prairie. Herbicide-treated pastures on the CTER produced more grasses and forbs than untreated controls (Engle et al. 1987). Both herbicides killed a high proportion of dominant overstory oak species, but woody understory species such as buckbrush (Symphocarpos orbiculatus), elm (Ulmus americana), and chittamwood (Bumelia lanuginona) were not reduced as much by triclopyr as by tebuthiuron (Stritzke et al. 1987). Competition by understory woody species resistant to the herbicide reduced production of herbaceous plants after triclopyr treatment. Prescribed burning, which provides a secondary control of resistant and resprouting brush species, was more effective on tebuthiuron than triclopyr pastures because of greater control of understory brush species. In both 1985 and 1986, burns were unable to penetrate many sites with a dense overstory because of inadequate fine fuel accumulation and presence of cool season herbaceous plants, which resulted in a mosaic pattern of burns (Engle et al. 1987).

Small mammal populations respond in general to herbicide-induced habitat alterations according to their individual habitat and forage requirements (Kirkland 1978, Borrecco et al. 1979, Santillo et al. 1989). For example, initial losses of vegetative cover following applications of 2,4,5-T was thought to increase predation losses in microtine populations (Kirkland 1978), while reductions in vegetative cover following applications of glyphosate had no impact on Peromyscus populations because of increases in plant and invertebrate food resources (Santillo et al. 1989). One must exercise caution in comparing studies on different herbicides because they vary in efficacy, selectivity, and site of application. These factors can produce very different post-treatment environments with respect to vegetation composition and structure. Tebuthiuron and triclopyr herbicides are primarily selective for woody species and some forbs. Other herbicides may be less effective on woody species (2,4-D, atrazine) or are completely nonselective (glyphosate) (Vallentine 1989). Previous studies examining the effects of herbicides on small mammal populations primarily have focused on 2,4-D and glyphosate applications to coniferous forest environments (Borrecco et al. 1979, Sullivan and Sullivan 1981, 1982, Anthony and Morrison 1985, Santillo et al. 1989).

Herbicide-induced alterations of plant species composition and structure resulted in dramatic changes in relative population densities of white-footed mice. Peak annual density of white-footed mice, averaged over the 3-year study, was 230% greater on herbicide-treated pastures than untreated controls. The white-footed mouse is a woodland species that prefers habitats of thick undergrowth (Kaufman et al. 1983), and favorable responses to increased understory shrub growth have been documented (Kirkland 1978, Borrecco et al. 1979). Response of white-footed mouse populations to herbicide applications on the CTER was probably a result of improved structural and forage characteristics. Stem density of understory shrub species was considerably greater on pastures treated with triclopyr than tebuthiuron, but differences were less between triclopyr and untreated controls (Stritzke et al. 1987). This suggests that in addition to structural attributes, other factors such as availability or quality of food resources promoted post-treatment increases in white-footed mouse populations. Although white-footed mice probably utilize tree and shrub mast as a primary food source (Baker 1968), their feeding strategy is known to be flexible (Drickamer 1976). Total herbaceous forage production (forbs and grasses) in 1986 averaged almost 50X greater on herbicide-treated pastures than untreated controls (Engle et al. 1987).

Populations of Peromyscus have been shown to respond favorably to additions of supplemental food with increased breeding and survival (Taitt 1985, Briggs 1986, Vessey 1987). Although all reproductive parameters did not change in response to experimental herbicide treatments, several indicators of male reproductive activity and percentage of juveniles recruited into the trapable population differed with untreated controls. Testes weights, frequency of scrotal males in summer, and percentage of juveniles in the population were all lowest in untreated control pastures. Merson (1979) reported significant reductions in testes weights and measures of spermatogenesis in white-footed mice subjected to moderate dietary restrictions. The lower frequency of juveniles from untreated controls, coupled with no difference in measures of female reproductive activity, suggests that survival of juveniles to trapable-age was lower on untreated control pastures. If the nutritional environment of herbicide-treated pastures was improved over untreated controls, the lack of any significant differences in adult female reproductive parameters is difficult to explain. Merson (1979) found female white-footed mice to be very sensitive to diet, with reduction of feed intake as low as 10% causing a significant decline in incidence of vaginal estrus.

The greater relative body condition scores and liver weights of white-footed mice from herbicide-treated pastures compared to untreated controls further supports our assessment that these treatments improved the overall nutritional quality of habitats. The observation that stomach content weights were greater on untreated control pastures compared to herbicide treatments could be a reflection of a need to consume larger quantities of poor quality forage to meet daily requirements. Merson (1979) reported significant reductions in liver weight in white-footed mice subjected to moderate dietary restrictions. However, body weight is apparently not a sensitive indicator of nutritional status (Merson 1979).

Population responses of the white-footed mouse to the herbicides triclopyr and tebuthiuron were also very different, with greater densities on those pastures treated with triclopyr. Structure of post-treatment habitats differed greatly between these two herbicides. Incomplete overstory removal and resprouting of woody species following triclopyr applications resulted in a more structurally complex habitat compared to tebuthiuron treatments (Stritzke et al. 1987). Forbs comprised a greater proportion of the standing crop biomass on triclopyr treatments compared to tebuthiuron treatments (Engle et al. 1987).

Relative importance of structural and nutritional attributes of habitats in explaining observed population differences between triclopyr and tebuthiruon treatments was difficult to determine. Although mean litter size of pregnant females was greater on triclopyr than burned tebuthiuron treatments, the only apparent differences in juvenile recruitment occurred in March 1986. Our observation that percentage of adult males with scrotal testes and stomach content weights were greater on tebuthiuron-treated pastures compared to those treated with triclopyr appeared contradictory and could not be explained. Other condition indicators that I measured did not suggest any differences in the nutritional quality of habitats between these two treatments.

White-footed mouse populations also responded to our prescribed burning treatments following herbicide applications. Unlike Peromyscus maniculatus populations which often respond favorably to burning as a result of increased seed availability (Tester 1965, Ahlgren 1966, Beck and Vogl 1972), white-footed mouse populations appear to avoid burned habitat (Beck and Vogl 1972). Senzota (1985) caught higher numbers of white-footed mice on unburned compared to burned tebuthiuron-treated rangeland, but differences were not significant.

Burning may have improved the nutritional quality of the habitat on the CTER without concomitant increases in population density, possibly because of negative changes in habitat structure. Spring burning of rangeland has been shown to increase the nutritive quality of veral plant species (Allen et al. 1976), and standing crop biomass of forbs on burned tebuthiuron and triclopyr treatments on the CTER exceeded their unburned counterparts by 250% and 35%, respectively in 1986 (Engle et al. 1987). The higher relative condition scores and spleen weights on burned than unburned pastures suggest that burning improved nutritional conditions. Despite the possibility of improved nutritional conditions on burned pastures, reproductive activity appeared to be greater on unburned treatments. For example, percent of adult females with perforate vulva and percentage of scrotal males (spring seasons) were higher on unburned treatments. Also, no pregnant females were caught on burned tebuthiuron treatments after the first spring and litter sizes were greater on unburned triclopyr treatments than burned tebuthiuron-treated pastures. Beck and Vogl (1972) reported that reductions in understory stem density of shrubs following burning had an adverse impact on habitat structure.

These results indicate that white-footed mouse populations are sensitive to alterations of structural and forage components of their habitat. Modifications such as those described in this study are not permanent, as succession of the plant community proceeds rapidly following herbicide treatment. The complete absence of reproduction among females in spring 1987, although difficult to explain, was probably a precursor to the decline and sustained low relative population densities observed throughout 1987 and 1988. Average forb production in 1986 declined 50% and 45% from 1985 levels on tebuthiuron- and triclopyr-treated pastures, respectively (Engle et al. 1987). Reduced forb production in 1986 following a peak in 1985 may have represented a major decline in the preferred food resources of the white-footed mouse. The lower condition scores of adult white-footed mice in spring 1987 compared to spring 1986 also suggests a decline in forage quality in this period. Forage quality is known to have positive effects on the reproductive potential of females (Merson 1979, Merson and Kirkpatrick 1982, Bomford and Redhead 1987).

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Table 1. Values for reproductive parameters of adult female and male white-footed mice for each trapping period.

Reproductive parameter	Year and Season																													
	1986												1987												1988					
	Spring			Summer			Fall			Winter			Spring			Summer			Fall			Winter			Summer			Winter		
	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE	N	MEAN	SE
Testes weight[a] (mg)	117	565	18	56	113	11	13	601	49	83	111	13	75	191	12	24	69	9	6	509	36	33	385	28	12	85	26	21	346	23
Seminal vesicle[a] weight (mg)	117	417	19	56	35	3	13	415	35	83	30	4	75	50	6	24	22	2	6	396	35	33	187	23	12	27	4	21	179	27
Litter size[b]	61	3.48	0.10	0			13	4.62	0.21	1	8.0	--	0			0			6	4.33	0.42	6	3.8	0.17	0			4	3.5	0.50
Uterine weight[a] (mg)	92	1115	183	38	49	4	34	1278	385	50	56	8	43	34	4	25	27	3	11	1130	472	19	154	29	4	34	2	17	718	429
Vulva perforate[c]	0			26 (19.2)			33 (75.7)			50 (20.0)			43 (11.6)			24 (08.3)			11 (63.6)			18 (55.5)			5 (0)			17 (41.2)		
Scars present[c]	0			35 (77.1)			32 (46.8)			47 (85.1)			42 (71.4)			25 (80.0)			10 (30.0)			18 (33.3)			5 (100)			17 (47.1)		

[a] N = total number of adults of which the reproductive parameter was measurable.

[b] N = total number of pregnant females.

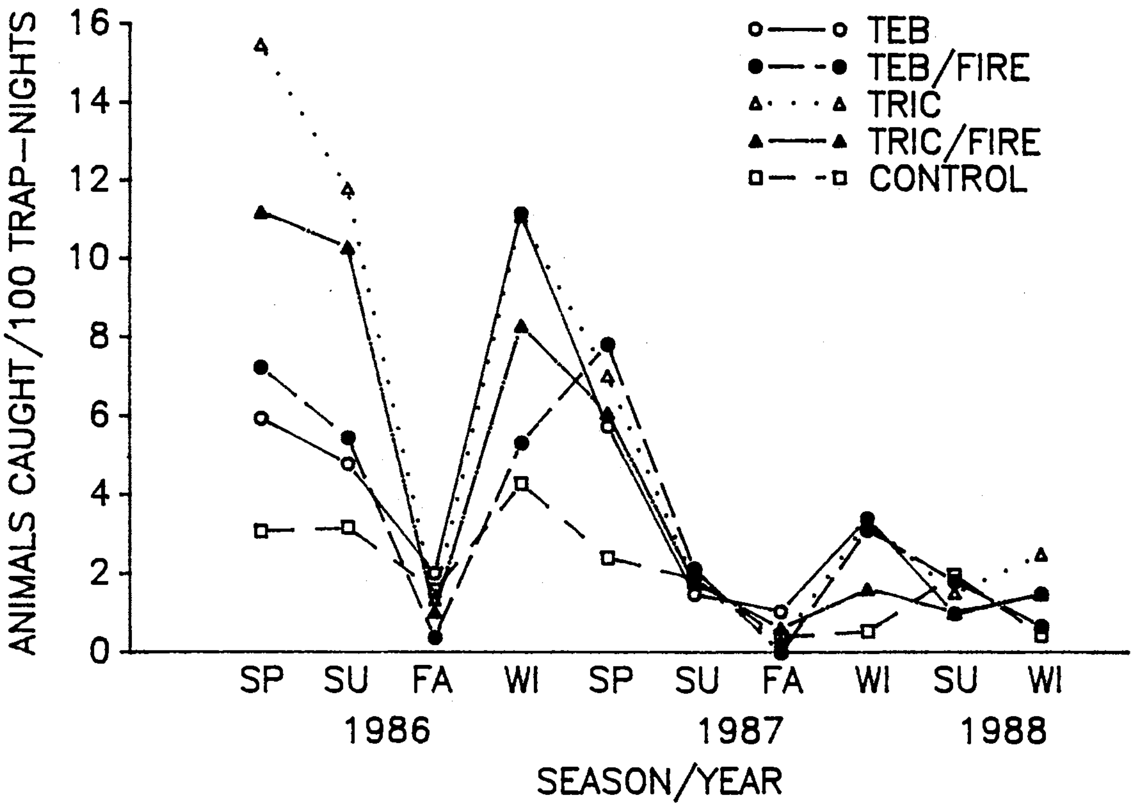
[c] N values and percentages.

Table 2. Mean, ±SE, and N values for condition score, body weight, and stomach content weight of adult white-footed mice caught in 1986 (stomach contents) and pooled years 1986 to 1988 (condition score, body weight). Also multiple range tests and specific contrast results.

Season	Tratement	Condition Score		Body Weight		Stomach contents	
		Male	Female	Male	Female	Male	Female
Spring	Tebuthiruon	24.61±0.39(39)	26.02±0.84(20)	22.87±0.37(39)	23.65±0.68(20)	0.240±0.039(24)	0.213±0.073(11)
	Tebuthiuron/fire	24.63±0.39(38)	24.97±0.44(38)	23.25±0.48(38)	23.55±0.48(38)	0.330±0.065(21)	0.339±0.065(26)
	Triclopyr	25.47±0.43(47)	26.70±0.75(36)	24.18±0.42(47)	25.93±0.70(36)	0.278±0.054(29)	0.378±0.070(27)
	Triclopyr/fire	25.35±0.31(49)	26.56±0.80(32)	22.92±0.32(49)	24.34±0.80(32)	0.234±0.040(32)	0.374±0.083(21)
	Control	23.01±0.31(19)	26.01±1.73(09)	22.23±0.33(19)	24.92±1.59(09)	0.310±0.067(07)	0.469±0.114(05)
Summer	Tebuthiuron	22.01±0.42(12)	22.97±0.90(08)	21.34±0.58(12)	21.61±0.74(08)	0.426±0.130(08)	0.611±0.152(04)
	Tebuthiuron/fire	23.40±0.42(13)	22.81±0.40(15)	22.19±0.58(13)	21.42±0.46(15)	0.635±0.131(07)	0.391±0.121(07)
	Triclopyr	23.10±0.47(21)	22.41±0.47(16)	22.47±0.54(21)	21.56±0.59(16)	0.320±0.052(14)	0.212±0.053(11)
	Triclopyr/fire	22.35±0.31(28)	22.35±0.65(15)	21.38±0.27(28)	21.54±0.66(16)	0.370±0.036(20)	0.519±0.131(12)
	Control	23.49±0.47(18)	22.21±0.98(14)	21.93±0.59(18)	21.85±0.61(14)	0.538±0.135(07)	0.450±0.216(03)
Fall	Tebuthiuron	23.82±0.77(07)	28.35±0.92(16)	22.72±0.61(07)	27.06±0.91(16)	0.606±0.502(02)	0.555±0.082(12)
	Tebuthiuron/fire	25.73 (01)	29.48±2.41(02)	26.24 (01)	30.18±2.03(02)	0.194 (01)	1.089±0.509(02)
	Triclopyr	23.39±1.04(03)	24.96±1.98(07)	22.45±0.31(03)	24.32±2.37(07)	0.112±0.069(03)	0.311±0.101(05)
	Triclopyr/fire	26.02 (01)	25.25±1.24(10)	23.94 (01)	25.10±1.35(10)	(00)	0.154±0.038(07)
	Control	24.14±0.62(07)	24.95±0.88(10)	23.69±0.74(07)	24.18±1.04(10)	0.400±0.131(06)	0.575±0.163(08)
Winter	Tebuthiuron	23.90±0.30(34)	24.30±0.55(25)	22.42±0.35(34)	23.21±0.66(25)	0.246±0.044(13)	0.228±0.075(12)
	Tebuthiuron/fire	24.70±0.58(18)	24.86±0.81(07)	22.88±0.70(18)	23.95±1.05(08)	0.156±0.046(07)	0.624 (01)
	Triclopyr	23.39±0.33(50)	25.01±0.72(23)	22.37±0.36(50)	23.97±0.71(23)	0.324±0.046(25)	0.365±0.094(10)
	Triclopyr/fire	24.69±0.45(23)	25.59±0.57(22)	23.13±0.49(23)	24.36±0.78(22)	0.272±0.056(15)	0.419±0.072(15)
	Control	23.40±0.71(12)	24.48±0.83(13)	22.72±0.76(12)	23.23±0.80(13)	0.404±0.069(07)	0.468±0.159(05)
LSD:[a] Season		fall spring winter summer		fall spring winter summer		summer fall winter spring	
Treatment		tric/f teb/f teb tric cont		tric teb teb/f tric/f cont		cont teb/f tric/f teb tric	
Contrast:		control vs treatment (P=0.022)		nothing significant		triclopyr vs tebuthiuron (P=0.027)	
		burned vs unburned (P=0.035)				control vs treatment (P=0.004)	

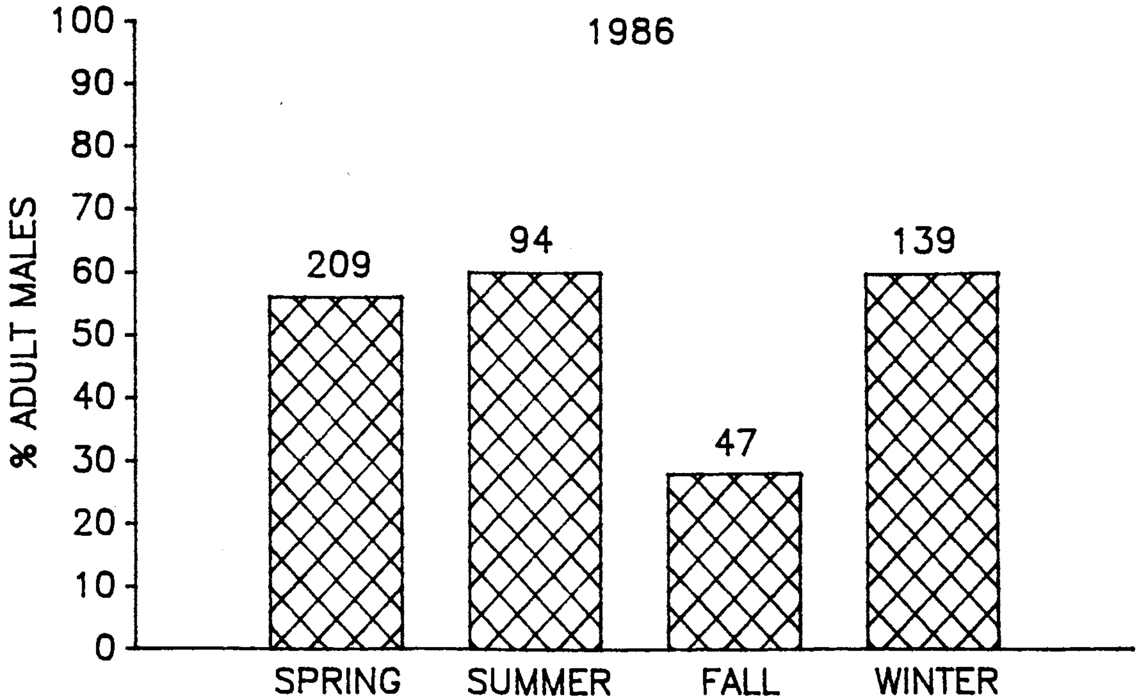
[a] Common underscore denotes no significant difference.

Figure 1. Total catch/unit effort of white-footed mice on the 5 experimental brush treatments from spring 1986 to winter 1988.



ANIMALS CAUGHT/100 TRAP-NIGHTS
16
14
12
10
8
6
4
2
0
TEB
TEB/FIRE
TRIC
TRIC/FIRE
CONTROL
SP
SU
FA
WI
SP
SU
FA
WI
SU
WI
1986
1987
1988
SEASON/YEAR

Figure 2. Differences in percent adult male white-footed mice among seasons in 1986 and 1987. Values above bars represent sample size (N).


1986
% ADULT MALES
100
90
80
70
60
50
40
30
20
10
0
209
94
47
139
SPRING
SUMMER
FALL
WINTER

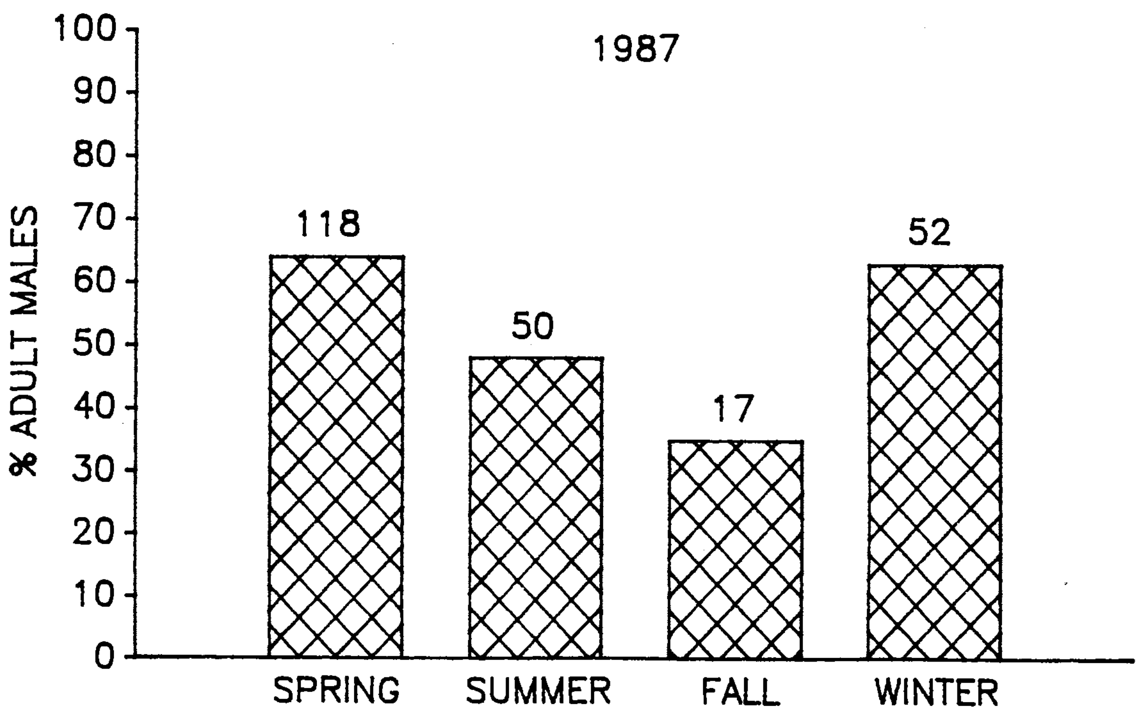
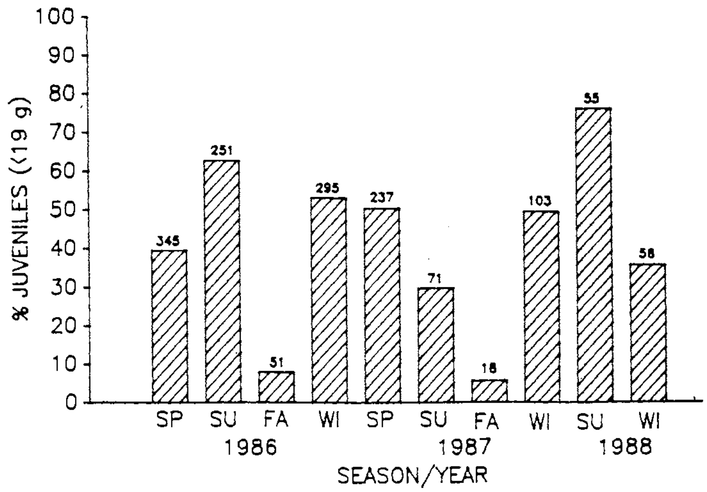
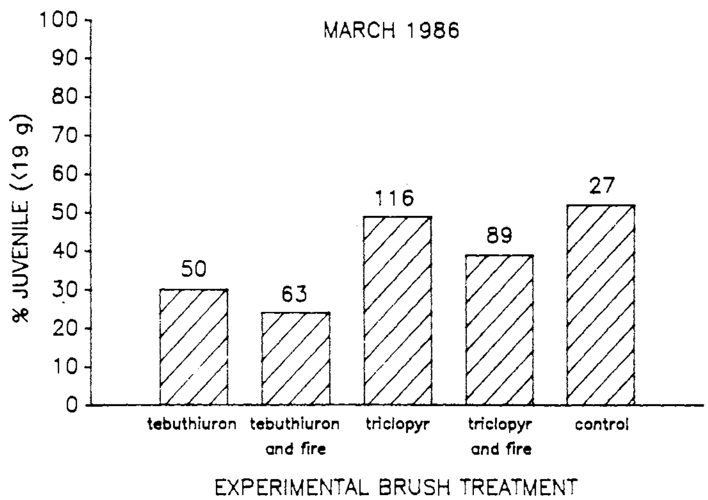

1987
% ADULT MALES
100
90
80
70
60
50
40
30
20
10
0
118
50
17
52
SPRING
SUMMER
FALL
WINTER

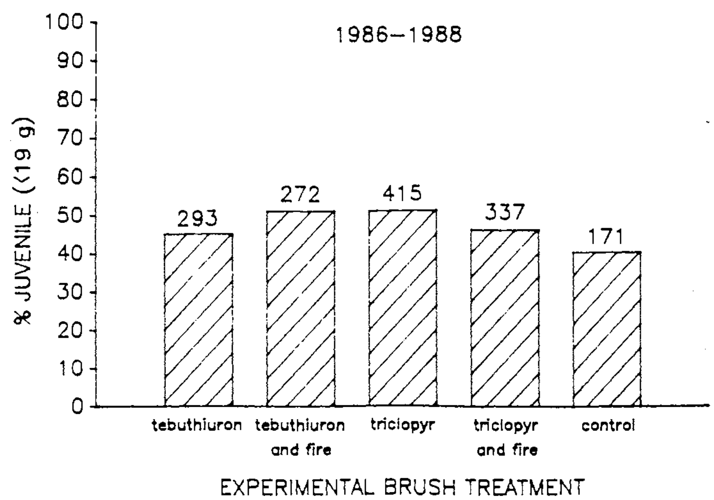
Figure 3. Seasonal trends in percent juvenile white-footed mice from spring 1986 to winter 1988 and differences among experimental brush treatments in March 1986 and among pooled years and seasons. Values above bars represent sample size (N).



100
90
80
70
60
50
40
30
20
10
0
% JUVENILES (<19 g)
345
251
51
295
237
71
18
103
55
58
SP SU FA WI SP SU FA WI SU WI
1986
1987
1988
SEASON/YEAR



MARCH 1986
% JUVENILE (<19 g)
100
90
80
70
60
50
40
30
20
10
0
50
63
116
89
27
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT



1986–1988
% JUVENILE (<19 g)
100
90
80
70
60
50
40
30
20
10
0
293
272
415
337
171
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

Figure 4. Seasonal trends in percent reproductively active (pregnant or lactating) adult female white-footed mice from spring 1986 to winter 1988. Values above bars represent sample size (N).

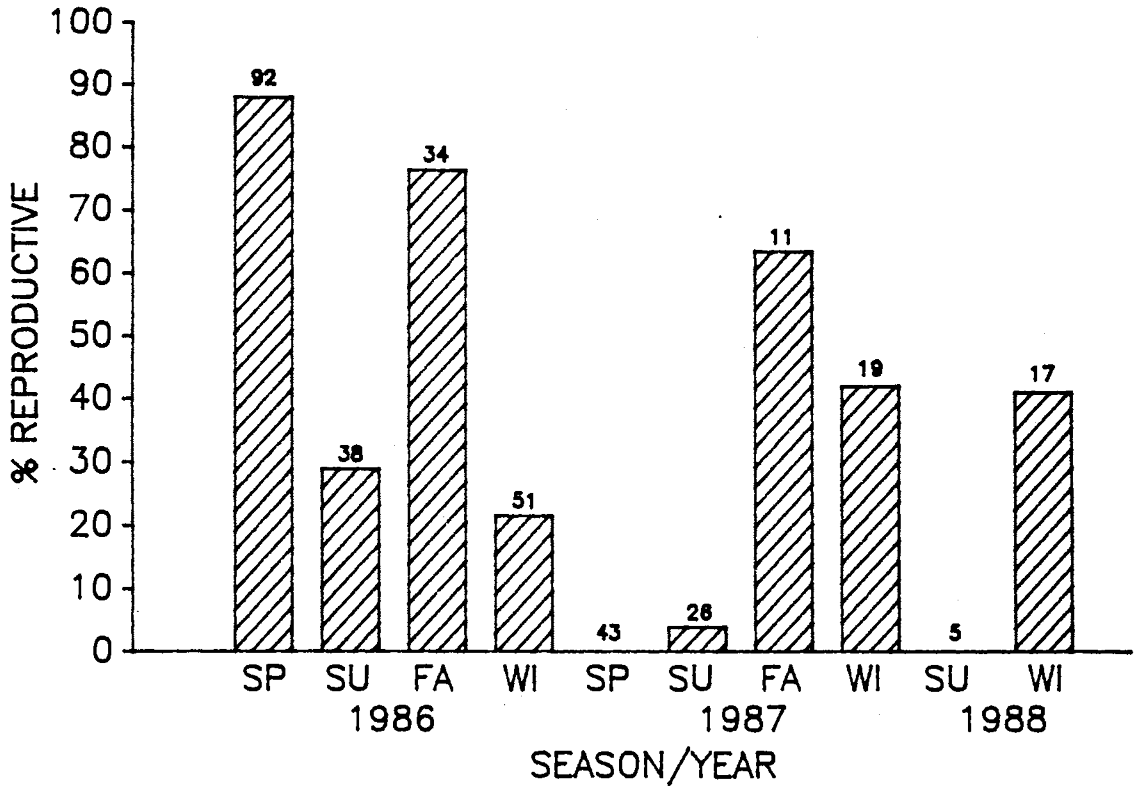
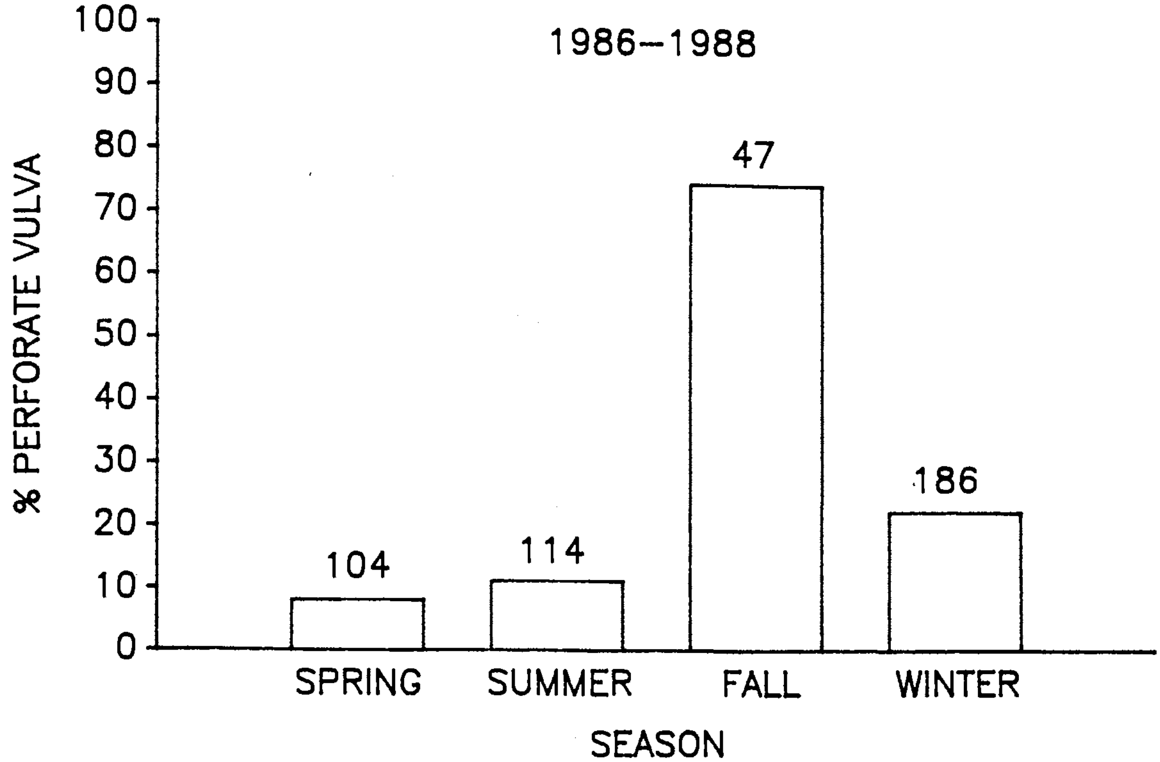

100
90
80
70
60
50
40
30
20
10
0
% REPRODUCTIVE
92
38
34
51
43
26
11
19
5
17
SP
SU
FA
WI
SP
SU
FA
WI
SU
WI
1986
1987
1988
SEASON/YEAR

Figure 5. Differences in adult female white-footed mice with a perforate vulva among seasons (years pooled) and experimental brush treatments (years and seasons pooled). Values above bars represent sample size (N).


1986–1988
% PERFORATE VULVA
100
90
80
70
60
50
40
30
20
10
0
104
114
47
186
SPRING
SUMMER
FALL
WINTER
SEASON

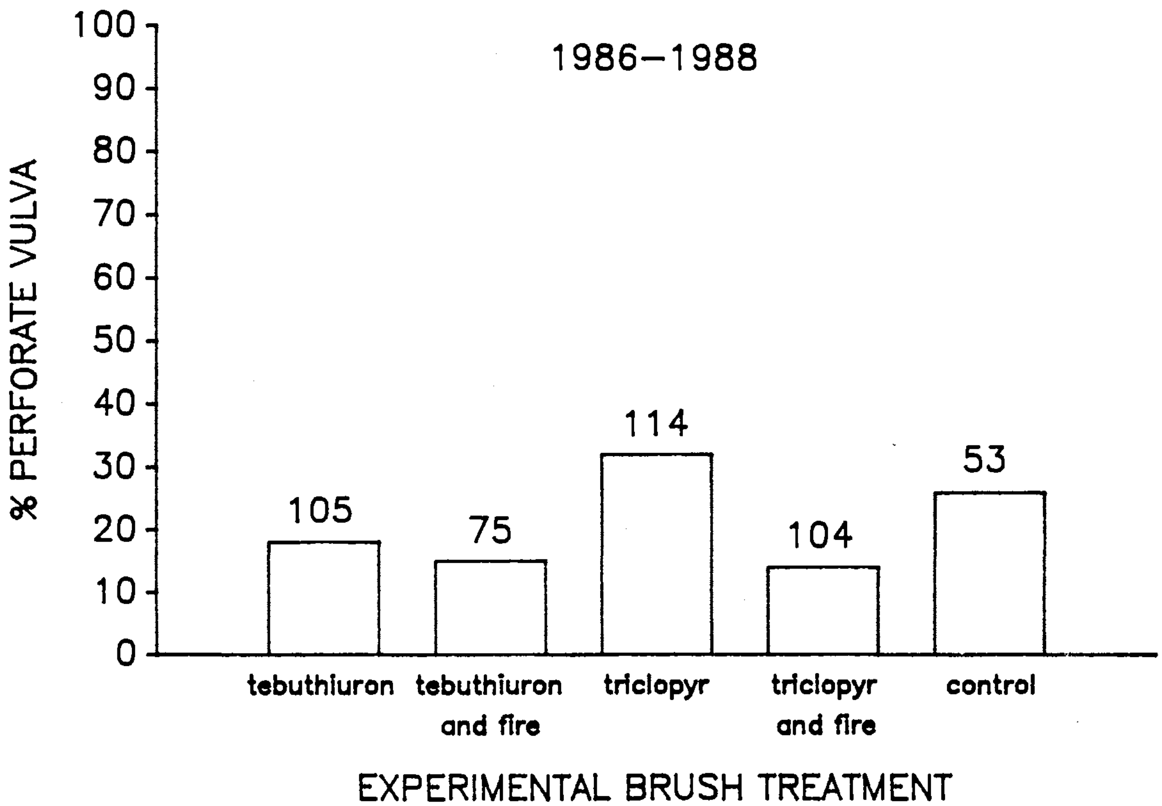
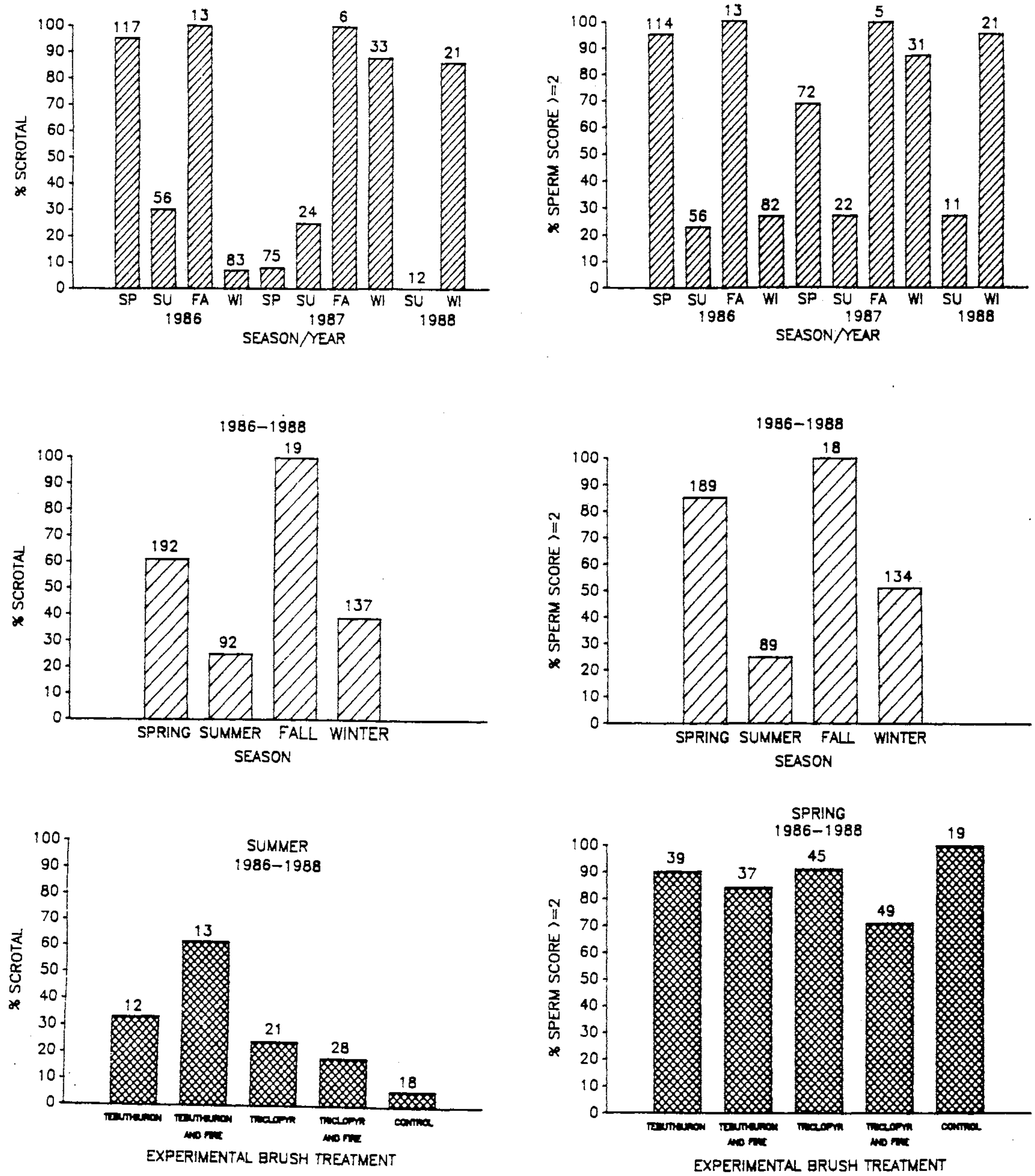
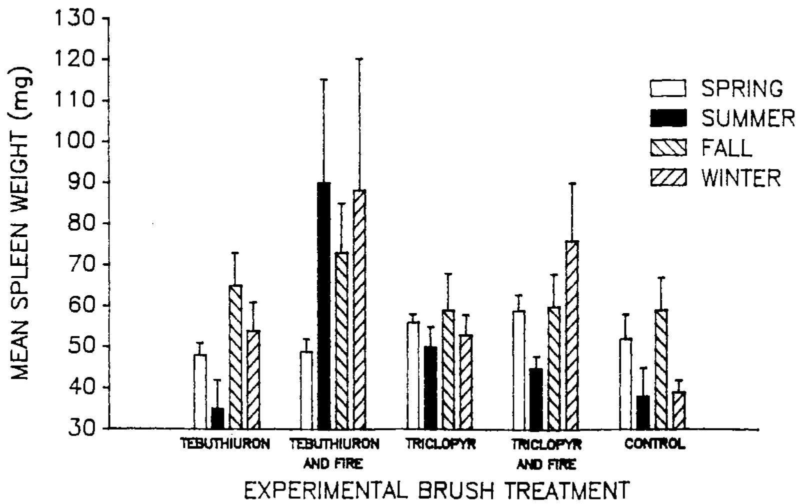

1986–1988
% PERFORATE VULVA
100
90
80
70
60
50
40
30
20
10
0
105
75
114
104
53
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

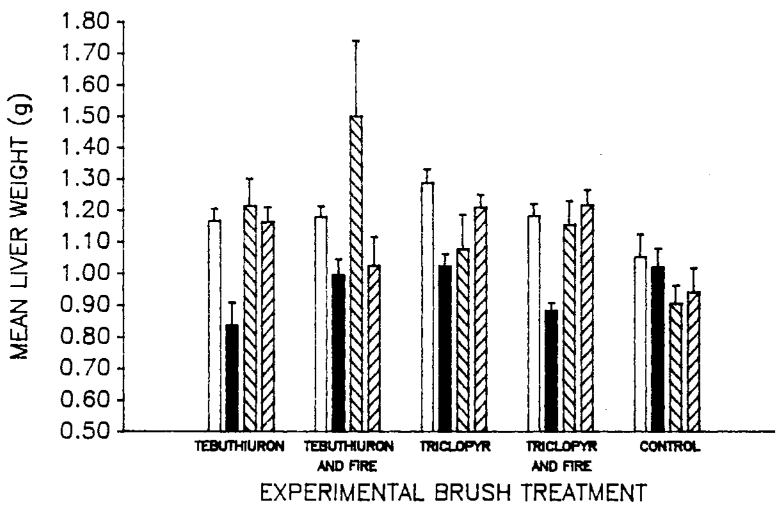
Figure 6. Trends in percent scrotal and relative sperm abundance scores in populations of adult male white-footed mice from spring 1986 to winter 1988 and differences among seasons (years pooled) and experimental brush treatments (summers and springs pooled, respectively). Values above bars represent sample size (N).

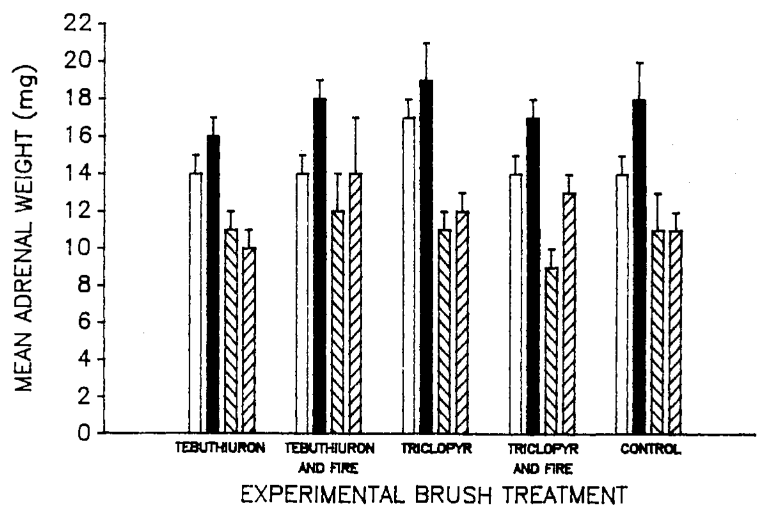


% SCROTAL
117
56
13
83
75
24
6
33
12
21
SP SU FA WI SP SU FA WI SU WI
1986
1987
1988
SEASON/YEAR
% SPERM SCORE)=2
114
56
13
82
72
22
5
31
11
21
SP SU FA WI SP SU FA WI SU WI
1986
1987
1988
SEASON/YEAR
1986–1988
% SCROTAL
192
92
19
137
SPRING SUMMER FALL WINTER
SEASON
1986–1988
% SPERM SCORE)=2
189
89
18
134
SPRING SUMMER FALL WINTER
SEASON
SUMMER
1986–1988
% SCROTAL
12
13
21
28
18
EXPERIMENTAL BRUSH TREATMENT
SPRING
1986–1988
% SPERM SCORE)=2
39
37
45
49
19
EXPERIMENTAL BRUSH TREATMENT

Figure 7. Differences in mean weight (+SE) of spleen, liver, and paired adrenal glands in populations of white-footed mice from experimental brush treatments in 1986.


MEAN SPLEEN WEIGHT (mg)
130
120
110
100
90
80
70
60
50
40
30
SPRING
SUMMER
FALL
WINTER
TEBUTHIURON
TEBUTHIURON AND FIRE
TRICLOPYR
TRICLOPYR AND FIRE
CONTROL
EXPERIMENTAL BRUSH TREATMENT


MEAN LIVER WEIGHT (g)
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
TEBUTHIURON
TEBUTHIURON AND FIRE
TRICLOPYR
TRICLOPYR AND FIRE
CONTROL
EXPERIMENTAL BRUSH TREATMENT


MEAN ADRENAL WEIGHT (mg)
22
20
18
16
14
12
10
8
6
4
2
0
TEBUTHIURON
TEBUTHIURON AND FIRE
TRICLOPYR
TRICLOPYR AND FIRE
CONTROL
EXPERIMENTAL BRUSH TREATMENT

Chapter III

POPULATIONS OF COTTON RATS (*SIGMODON HISPIDUS*) IN RELATION TO HERBICIDE AND PRESCRIBED BURNING IN CENTRAL OKLAHOMA

Abstract: I examined the influence of 5 experimental brush treatments on relative population density, reproduction, and body condition of cotton rats (*Sigmodon hispidus*) on cross timbers rangeland in Oklahoma. Treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning, and untreated controls. A total of 707 cotton rats was collected from March 1986 through December 1988. Relative population density varied among seasons and experimental treatments. Peak density occurred on all experimental treatments except controls in December 1986 which was followed by a decline in March 1987, remaining low through the rest of the study. Relative population density was highest on tebuthiuron and burned treatments compared to triclopyr and unburned treatments. Seasonal variation in reproductive activity was evident with peaks in summer and all. Percentage of reproductively active adult females was less than expected on triclopyr treatments compared to tebuthiuron. Testes position and weight and spermatogenesis were not influenced by experimental treatment, but seminal vesicle glands were heaviest in males from triclopyr treatments. Body weights and relative conditions score were highest in fall and summer. Mean liver and spleen weights were lightest in winter and paired adrenal gland weights were heaviest in spring and winter for males and summer for females. Mean stomach content weight, the only condition parameter affected by experimental treatment, was heaviest in males from control pastures.

Studies of the cotton rat (Sigmodon hispidus) have shown habitat variation as a major determinant of demographic variation (Cameron 1977, Kincaid and Cameron 1985). Although cotton rats have been reported in a wide variety of habitats, it appears they require and prefer habitats containing dense herbaceous vegetation, often with overhead cover from shrubs (Goertz 1964, Fleharty and Mares 1973, Kincaid et al. 1983). Changes in any of these structural and resource attributes of the habitat could be expected to alter certain demographic characteristics of resident cotton rat populations. For example, man-induced perturbations from such practices as burning (Stoddard 1931, Baker 1940, Stickel and Stickel 1949), overgrazing (Phillips 1936, Baker 1940, McCulloch 1959, Goertz 1964), and mechanical brush removal (Powell 1968) alter important habitat components with concommitant demographic changes in resident cotton rat populations.

Habitat alterations resulting from herbicides and herbicides with prescribed burning are often pronounced (Scifres 1980), however, responses of small mammal populations to these perturbations have received scant attention. Although demographic responses of several small mammal species to the herbicides 2,4-D (Keith et al. 1959), 2,4,5-T (Kirkland 1978), atrazine (Borrecco et al. 1979), and glyphosate (Sullivan and Sullivan 1982, Santillo et al. 1989) have been explored in a variety of ecosystems, responses of cotton rat populations to these practices are not completely known. Two herbicides, tebuthiuron (N-[5-(1,1-dimehtyl-ethyl)-1,3,4-thiadiazol-2 yl]-N,N'-dimethylurea), and triclopyr ([(3,5,6- trichloro-2-pyridinyl) oxyl acetic acid), are commonly used for managing brush-dominated rangelands. Despite increased use, relatively little is known about small mammal responses to habitat modifications that occur after tebuthiuron and triclopyr applications. Research on these herbicides is limited essentially to the work of Senzota (1985) who monitored responses of cotton rat populations to prescribed burning on rangeland treated with tebuthiuron.

The primary objectives of my study were to evaluate demographic, reproductive, and condition responses of cotton rat populations to tebuthiuron and triclopyr, used in combination with and without annual prescribed burning, in central Oklahoma on oak-dominated cross timbers vegetation. This area is representative of the cross timbers vegetation type (Ewing et al. 1984), which accounts for nearly 5 million ha of rangeland in Oklahoma, Kansas, and Texas (SCS 1981). The desire of livestock producers to more efficiently utilize rangeland in the Cross Timbers for grazing has led to widespread use of herbicides and fire for managing brush.

METHODS

Study area.--This study was conducted on the Cross Timbers Experimental Range (CTER), located approximately 11 km southwest of Stillwater, Oklahoma. The CTER encompasses 648 ha of typical cross timbers rangeland composed of upland forest with interspersed grassland-cedar savannas. The CTER has a long land use history consisting of cultivation, cropland abandonment, and livestock grazing which has resulted in a general decline in site potential and range condition (Ewing et al. 1984). Upland forest habitats are dominated by post oak

(*Quercus stellata*) and black-jack oak (*Q. marilandica*) in the overstory, and eastern redcedar (*Juniperus virginiana*), rough-leaf dogwood (*Cornus drummondii*), redbud (*Cercis canadensis*), American elm (*Ulmus americana*), and coralberry (*Symphoricarpos orbiculatus*) in the understory. Herbaceous ground cover is primarily composed of little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), rosette panicgrass (*Panicum oligosanthes*), and western ragweed (*Ambrosia psilostachya*).

Experimental design.--The CTER was divided into 20 32.4 ha experimental pastures representing 4 replications of 5 experimental brush treatments in a randomized block design. Pastures were assigned to respective blocks according to their similarity in total woody canopy cover and soils. The 5 experimental treatments include: (1) tebuthiuron, a soil applied herbicide (Elanco Products Co., Division of Eli Lilly and Co., Indianapolis, Indiana 46285), applied aerially at 2.2 kg per ha in March 1983; (2) tebuthiuron (as with treatment #1) with annual prescribed burning beginning April 1985; (3) triclopyr, a foliage applied herbicide (Dow Chemical Co., Midland, Michigan 48674), applied aerially at 2.2 kg per ha in June 1983; (4) triclopyr (as with treatment #3) with annual prescribed burning beginning in April 1985; and (5) untreated control. All experimental pastures were fenced and moderately grazed by yearling cattle from April to September of each year.

Animal collection.--Cotton rat populations were censused seasonally (Mar, Jun, Sep, Dec) in 1986 and 1987 and biannually (Jun and Dec) in 1988 for a total of 10 sampling periods. For each sampling period 2 replications of each experimental treatment were censused using removal trapping on a randomly placed 8 x 8 (1.1 ha) grid with 15 m spacing between grid points. Upland forest habitat was censused, and trapping grids were relocated before each sampling period so that no area within an experimental pasture was trapped more than once. I also alternated the replications censused after every two successive sampling periods. Museum specials (128 each) and Victor Rat Traps (32 each) were evenly distributed on each grid; traps were placed within a 1-m radius of each grid point. A peanut butter and rolled oat mixture and sliced apples were used as bait. Each grid was trapped for 3 consecutive nights with daily removal of all captures. Relative density was calculated on a catch/unit effort basis and expressed as the number of animals caught/100 trap-nights. A trap-night was defined as 1 snap-trap set for a single 24-hour period. Catch per unit effort values were calculated for each treatment replication, and corrections were made for traps sprung by all causes (Nelson and Clark 1973).

Collected animals were returned to the laboratory and total, body, tail, and hindfoot lengths ($\pm$1 mm) and body weight ($\pm$0.1 g) determined. Animals $\geq$60.0 g were classified as adults while those $\leq$59.9 g were considered juveniles (Odum 1955). Reproductive status of each male was assessed by recording testes position (scrotal, abdominal), epididymal sperm smear score, and weights of the testes and seminal vesicle gland. The presence of spermatozoa in the epididymis was ascertained by cutting the caudal pole, extruding its contents, and smearing across a glass slide. Slides were examined microscopically, and the relative abundance of sperm was assessed assigning a numerical rank of 0 (none), 1 (trace), 2 (moderate), and 3 (abundant). The condition of the vulva of each female was recorded as perforate or imperforate. Females were classified as pregnant only when embryos were grossly visible upon necropsy. Embryos and uterine scars were enumerated when present. Females were recorded as lactating if mammary tissue was conspicuous with hair-free areas surrounding the nipples. Females were considered reproductively active when pregnant or lactating. Animal condition was assessed by examining weights (±0.1 mg) of liver, spleen, adrenal glands, and oven-dry stomach contents. Contents were removed from each stomach and dried to constant weight at 55 C. A general condition index was calculated for each animal as the proportion of body weight to body length.

<u>Statistical Analyses</u>.--Differences among experimental treatments and seasons in frequency distributions for age and sex ratios and male (testes position, sperm abundance scores) and female (reproductive status, vulva condition, presence of uterine scars) reproductive parameters were analyzed by chi-square analysis (Koopmans 1981). Relative population density estimates were arcsine transformed (Sokal and Rohlf 1981) and differences among experimental treatments and seasons tested by analysis of variance (SAS 1985). Morphometric and condition parameters (body weight, organ and gland weights, condition score) were independently rank transformed prior to data analysis as a method to analyze non-normally distributed data (Conover and Iman 1981). Main and interactive effects of experimental brush treatment and season

were examined by analysis of variance for the rank transformed data (Conover and Iman 1981). Specific contrasts were used in all analysis of variance procedures to compare differences between major brush treatment components (tebuthiuron vs. triclopyr, burned vs. unburned, brush treated vs. untreated controls).

RESULTS

Population characteristics.--A total of 707 cotton rats was captured during the 3-year study. Relative population density differed among seasons ($P < 0.001$) and experimental treatments ($P < 0.001$). Cotton rat populations on all experimental brush treatments, except untreated controls, experienced a peak in relative density in winter 1986 (Fig. 1). Highest relative density reached was 8.29 animals/100 trap-nights on burned tebuthiuron-treated pastures in winter 1986. Cotton rats were captured on untreated control pastures only in summer and fall 1986 and relative density never exceeded 0.92 animals/100 trap-nights. The amplitude of seasonal fluctuations in relative population density was most pronounced in 1986 when populations in burned tebthiuron-treated pastures experienced an 8-fold increase from spring to winter. When experimental brush treatments were analyzed separately, only cotton rat populations in tebuthiuron ($P < 0.005$) and triclopyr ($P < 0.050$) treatments subjected to prescribed burning demonstrated significant seasonal variation. All populations remained essentially stable through 1987 and 1988.

Specific contrasts revealed that relative population density of cotton rats in pastures treated with herbicides were significantly ($P <$

0.001) greater than untreated control pastures. Relative population density was also significantly greater on pastures treated with tebuthiuron ($\underline{P} < 0.001$) and pastures receiving annual prescribed burns ($\underline{P} < 0.025$) compared to triclopyr and unburned treatments, respectively. Overall, annually burned tebuthiuron-treated pastures had the highest relative population densities of cotton rats compared to other treatments during the 3-year study.

Sex ratios of cotton rat populations showed no significant relationship ($\underline{P} < 0.100$) to season or experimental brush treatment. Overall, males comprised 55.0% of the total sample. Although juvenile cotton rats were collected in all sampling periods, percentage of juveniles in populations fluctuated greatly ($\underline{X}^2 = 28.9$, 3 df, $\underline{P} < 0.001$) among pooled seasons (Fig. 2). Juveniles comprised a greater than expected proportion of the population in summer and fall and less than expected in spring and winter. Seasonal differences in percentage of juveniles were most pronounced in 1986. Percentage of juveniles in cotton rat populations differed significantly ($\underline{X}^2 = 12.1$, 4 df, $\underline{P} <$ 0.025) among experimental brush treatments (all years pooled), with a greater than expected ($\underline{X}^2 = 10.5$, 1 df, $\underline{P} < 0.005$) proportion of juveniles on burned compared to unburned treatments. Differences in percentage of juveniles between burned and unburned treatments were most pronounced in 1986 ($\underline{X}^2 = 9.6$, 1 df, $\underline{P} < 0.005$) and 1988 ($\underline{X}^2 = 5.5$, 1 df, $\underline{P} < 0.025$) (Fig. 2).

Reproductive activity.--Reproductively active adult female cotton rats were observed throughout the study except in spring and winter 1987 and winter 1988 (Fig. 3). Distinct seasonal peaks of reproductive activity were evident with greatest reproductive activity occurring in fall 1986 and 1987 where 93% and 100% of adult females were reproductively active, respectively. Percentage of adult females that were reproductively active was greater than expected in fall and less than expected in winter and spring ($\underline{X}^2 = 96.1$, 3 df, $\underline{P} < 0.001$). Percentage of adult females that were reproductively active (all seasons and years pooled) was lower ($\underline{X}^2 = 3.9$, 1 df, $\underline{P} < 0.050$) than expected in triclopyr treatments compared to those treated with tebuthiuron. No other experimental treatment differences were observed for reproductive activity of females. Pregnant females were observed in 7 of 10 sampling periods during the course of the study (Fig. 3). In utero litter size of pregnant cotton rats ranged from 3 to 12 ($\overline{X} = 6.55 \pm 0.23$ SE fetuses/pregnant female) and no season or experimental brush treatment differences were observed.

The proportion of adult females with a perforate vulva (all years pooled) differed significantly ($\underline{X}^2 = 40.5$, 3 df, $\underline{P} < 0.001$) among seasons, being greater than expected in fall and less than expected in winter compared to other seasons (Fig. 4). Percentage of adult females with a perforate vulva (all seasons and years pooled) approached greater ($\underline{X}^2 = 3.4$, 1 df, $\underline{P} < 0.100$) than expected levels in pastures treated with tebuthiuron compared to triclopyr. The percentage of adult females with uterine scars (overall 36%) did not differ ($\underline{P} > 0.100$) among seasons or experimental brush treatments.

The percentage of adult male cotton rats with scrotal testes (all years pooled) differed ($\underline{X}^2$ = 121.3, 3 df, $\underline{P}$ < 0.001) among seasons with a greater than expected proportion in summer and fall compared to spring and winter (Fig. 5). Experimental brush treatments had no significant ($\underline{P}$ > 0.100) influence on the percentage of adult males with either scrotal testes or relative sperm abundance score $\geq$ 2. Season also influenced ($\underline{X}^2$ = 120.4, 3 df, $\underline{P}$ < 0.001) percentage of adult males with relative sperm abundance scores $\geq$ 2 (all years pooled) with greater than expected percentages in summer and fall compared to spring and winter.

Mean weights of testes and seminal vesicle glands differed significantly ($\underline{P}$ < 0.001) among pooled seasons and complemented observed trends in reproductive activity based on testes position and relative sperm abundance scores (Fig. 5). Multiple range tests showed mean weights of testes and seminal vesicle glands for each season to differ from all others and were heaviest in summer and lighest in winter. Although mean testes weight did not differ ($\underline{P}$ > 0.100) among experimental brush treatments, specific contrasts showed seminal vesicle gland weights of adult cotton rats collected from triclopyr treatments to be significantly ($\underline{P}$ < 0.020) heavier than those from tebuthiuron-treated pastures.

Condition.--Body weights and relative condition scores of adult cotton rats were used as gross indices of body condition. No sex differences ($\underline{P}$ > 0.100) were observed relative to body weight or condition score and therefore, males and females were combined for statistical analyses. Mean ranked body weights and condition scores differed significantly ($P < 0.001$) among seasons. Multiple range tests indicated that mean adult body weights and condition scores in fall and summer (weight, 111.4 ± 3.1 SE g; condition score, 71.0 ± 1.5) were greater than in spring and winter (weight, 87.8 ± 1.6 SE g; condition score, 60.3 ± 0.8). Experimental brush treatments had no influence ($P >$ 0.100) on either body weight or condition score of adult cotton rats.

Mean stomach content weights differed ($P < 0.024$) between sexes and were analyzed seperately for males and females. Dried stomach content weights of males caught on control pastures (1.53 ± 0.14) weighed more ($P < 0.050$) than those from herbicide-treated pastures (0.82 ± 0.06). Season had no significant ($P > 0.100$) influence on stomach content weight of adult male cotton rats. Mean stomach content weights of adult females not differ ($P > 0.100$) among experimental brush treatments, but were influenced significantly ($P < 0.001$) by season. Mean stomach content weights of females collected in summer (1.10 ± 0.11) and fall (1.37 ± 0.15) were heavier than in winter (0.78 ± 0.09).

Liver, spleen, and paired adrenal gland weights of adult cotton rats were used as relative indicators of stress (Christian 1965) (Fig. 6). There were no differences ($P > 0.100$) in mean ranked liver and spleen weights between male and female adult cotton rats, so sexes were pooled for statistical analyses. Mean ranked liver and spleen weights of adults did not differ ($P > 0.100$) among experimental brush treatments. However, seasonal differences were apparent for both liver ($P < 0.040$) and spleen ($P < 0.001$) weights. Mean ranked liver and spleen weights were heaviest from spring to fall and lightest in winter.

Mean weights of paired adrenal gland differed ($\underline{P} < 0.001$) between sexes, but were not significantly ($\underline{P} > 0.100$) influenced by experimental treatments. However, seasonal differences were significant for both males ($\underline{P} < 0.001$) and females ($\underline{P} < 0.006$). Multiple range test indicated that weights of paired adrenal glands were heavier in spring and winter than fall for males and heavier in summer than winter for females (Fig. 6).

DISCUSSION

Experimental herbicide treatments produced vivid alterations in vegetation composition and structure of habitats compared to untreated controls. Herbicide-treated pastures produced more herbaceous vegetation than untreated control pastures (Engle et al. 1987). Although both herbicides killed a high proportion of dominant overstory oak species, woody understory species such as coralberry, American elm, and chittamwood (Bumelia lanuginosa) were not controlled as much by triclopyr as by tebuthiuron (Stritzke et al. 1987). Eastern redcedar and green-briar (Smilax sp.) were not controlled by either herbicide. Competition by understory brush species reduced production of herbaceous plants after triclopyr treatment. Prescribed burns were unable to penetrate most brushy upland sites because of an inadequate acumulation of fine fuel and presence of cool season grasses and resulted in a mosaic pattern of burns (Engle et al. 1987).

The composition and structural attributes of vegetation on herbicide-treated experimental pastures had a definite positive impact on populations of cotton rats, especially in 1986, the year after burn treatments commenced. The most obvious difference in habitat structure between untreated control pastures and those treated with tebuthiuron or triclopyr was the amount of herbaceous ground cover. Forb and grass biomass combined on the CTER was almost 50X greater on herbicide-treated pastures than untreated controls in 1986 (Engle et al. 1987). Goertz (1964) noted a strong relationship between densities of cotton rat populations and the amount of grass production in the cross timbers vegetation type. Strong preferences of cotton rats for grass-dominated habitats have also been reported for populations in Texas (Kincaid and Cameron 1985) and Kansas (Fleharty and Mares 1973).

Tebuthiuron and triclopyr undoubtedly increased the availability of both security cover and forage resources compared to untreated controls. However, the relative importance of these two resources in explaining observed differences in relative population density could not be determined with certainty. Quality of forages has been shown to improve following applications of herbicides such as tebuthiuron used with prescribed fire (Bogle et al. 1989) and without prescribed fire (Masters and Scifres 1984, Biodini et al. 1989). I was unable to detect significant differences in any condition or stress indicators, with the exception of stomach content weights, between untreated control and herbicide-treated pastures. Obviously, this could have been partly due to the extremely small number of cotton rats collected from untreated control pastures; a larger sample size may have increased my ability to detect differences. My observation that adult males collected from untreated control pastures had heavier stomach content weights compared to herbicide-treated pastures suggests these animals might have increased their intake as a result of consuming forage of a lower quality.

Because different types of herbicides vary greatly in their effectiveness and plant species susceptibility, it is difficult to make comparisons with other studies. For example, tebuthiuron and triclopyr selectively kill woody plant species, while permitting the release of understory grass species. Small mammal responses to the herbicides tebuthiuron and triclopyr have not been previously examined. Senzota (1985) monitored the responses of small mammal populations inhabiting tebuthiuron-treated rangeland to prescribed burning, but did not directly evaluate their response to tebuthiuron. Glyphosate herbicide applications to forest clearcuts have a detrimental impact on herbivorous small mammals as a result of herbicide-induced reductions in herbaceous and shrub cover (D'Anieri et al. 1987, Santillo et al. 1989). Similar responses have been reported following applications of 2,4-D (Johnson and Hansen 1969, Borrecco et al. 1979) and 2,4,5-T (Kirkland 1978).

Cotton rat populations also responded differently to the herbicides tebuthiuron and triclopyr. Triclopyr and tebuthiuron produced remarkably disparate habitat structure. Higher relative population densities were observed on those pastures treated with tebuthiuron compared to triclopyr-treated pastures. The effective reduction of woody overstory and control of resprouting after tebuthiuron treatment (Stritzke et al. 1987) promoted greater herbaceous plant production. Standing crop biomass of current annual grass growth on tebuthiuron-treated pastures averaged 40% more than triclopyr treatments in 1986 (Engle et al. 1987).

There were no apparent differences in recruitment of cotton rats, as measured by the percentage of juveniles collected, between these two herbicide treatments. However, the percentage of adult females that were reproductively active and had a perforate vulva were higher on tebuthiuron than triclopyr-treated pastures. These data tend to suggest that reproductive activity of adult females was influenced by the herbicide, and survival of juveniles to a trapable-age was not. This would indicate that nutritional aspects were of greater importance than cover in explaining the observed differences in relative population density. The importance of an adequate dietary intake in maintaining estrus, pregnancy, and lactation has been demonstrated in white-footed mice (Peromyscus leucopus) and cotton rats (Merson and Kirkpatrick 1982, Mattingly and McClure 1985).

Although uniform burns were not achieved on upland sites, mosaic patterns of burned and unburned habitat evidently had a positive influence on cotton rat populations. Higher relative population densities were observed on both burned tebuthiuron and triclopyr treatments. Burning on the CTER reduced standing crop biomass of current annual grass growth on both herbicide treatments by 3-17% from 1985 to 1986, but increased forb production (Engle et al. 1987). Standing crop biomass of forbs on burned tebuthiuron and triclopyr treatments exceeded their unburned counterparts by 250% and 35%, respectively. Although grasses comprise a major component of the cotton rat diet (Fleharty and Olsen 1969), forbs are also important, especially in spring (Kincaid and Cameron 1985). Spring burning of rangeland increases nutritive quality of several plant species (Allen et al. 1976).

Several investigators have examined effects of burning on small mammal populations with variable results (Beck and Vogl 1972, Crowner and Barrett 1979, Kaufman et al. 1983). The lack of consistency among these various burning studies is due in part to the great difficulty in standardizing intensity of prescribed burns. Even within a burn, differences in treatment intensity exist as a result of microclimate variation. Response of a small mammal species to a prescribed burn is undoubtedly dependant on both structural (Senzota 1985) and food (Kaufman et al. 1988) attributes of the habitat following the burn. Senzota (1985) noted that cotton rat populations inhabiting burned tebuthiuron-treated rangeland decreased in abundance compared to unburned tebuthiuron-treated areas. However, he found that populations returned to preburn densities after ground cover was restored within 6-8 months. I did not observe this type of response on the CTER, as relative population densities of cotton rats on burned treatments almost always exceeded their unburned counterparts over the 10 seasons sampled. This would tend to support our assessment that burning improved the nutritional quality of cotton rat habitat.

It is not completely clear why cotton rat populations in herbicide-treated pastures declined in relative density in 1987 and 1988 following a winter peak in 1986. Flucuations of this type have been described previously for cotton rats (Fleharty et al. 1972) and have been attributed to a variety of biotic and environmental factors. Reductions in herbaceous forage production on herbicide-treated pastures from 1986 to 1988 may have contributed to the decline in relative density on the CTER. Standing crop biomass of current annual growth for grass and forbs combined declined 40-75% from 1986 to 1988 on herbicide-treated pastures (D. M. Engle, unpubl. data). Similar post-herbicide treatment reductions in grass and forb production have been reported previously (Stritzke et al. 1975).

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Figure 1. Total catch/unit effort of cotton rats on the 5 experimental brush treatments from spring 1986 to winter 1988.

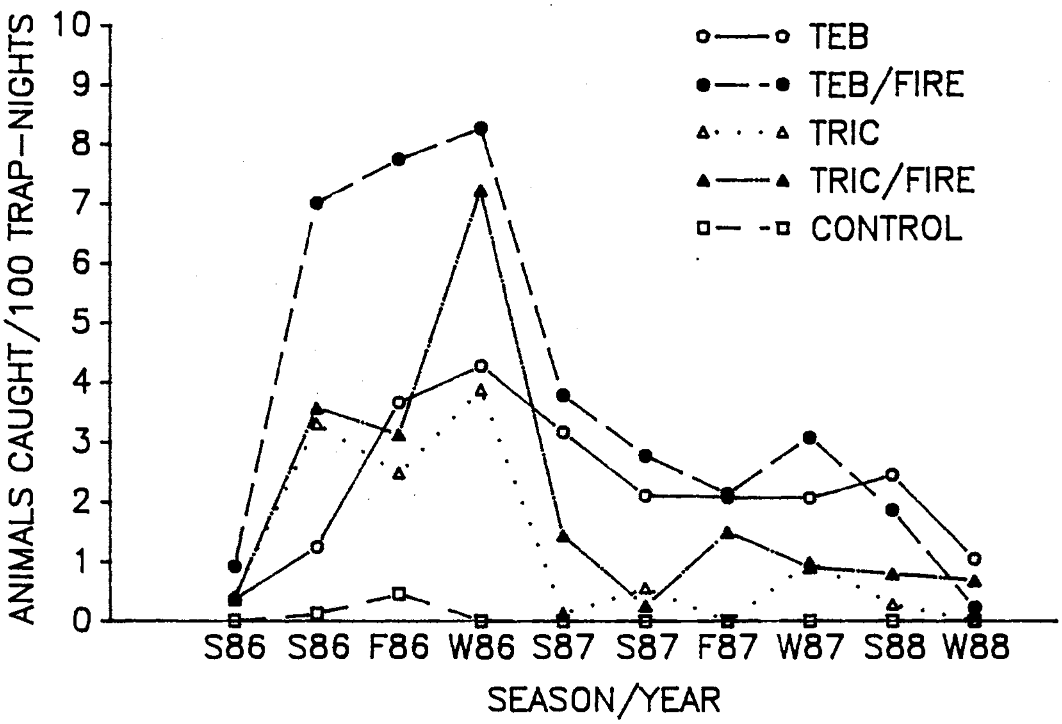
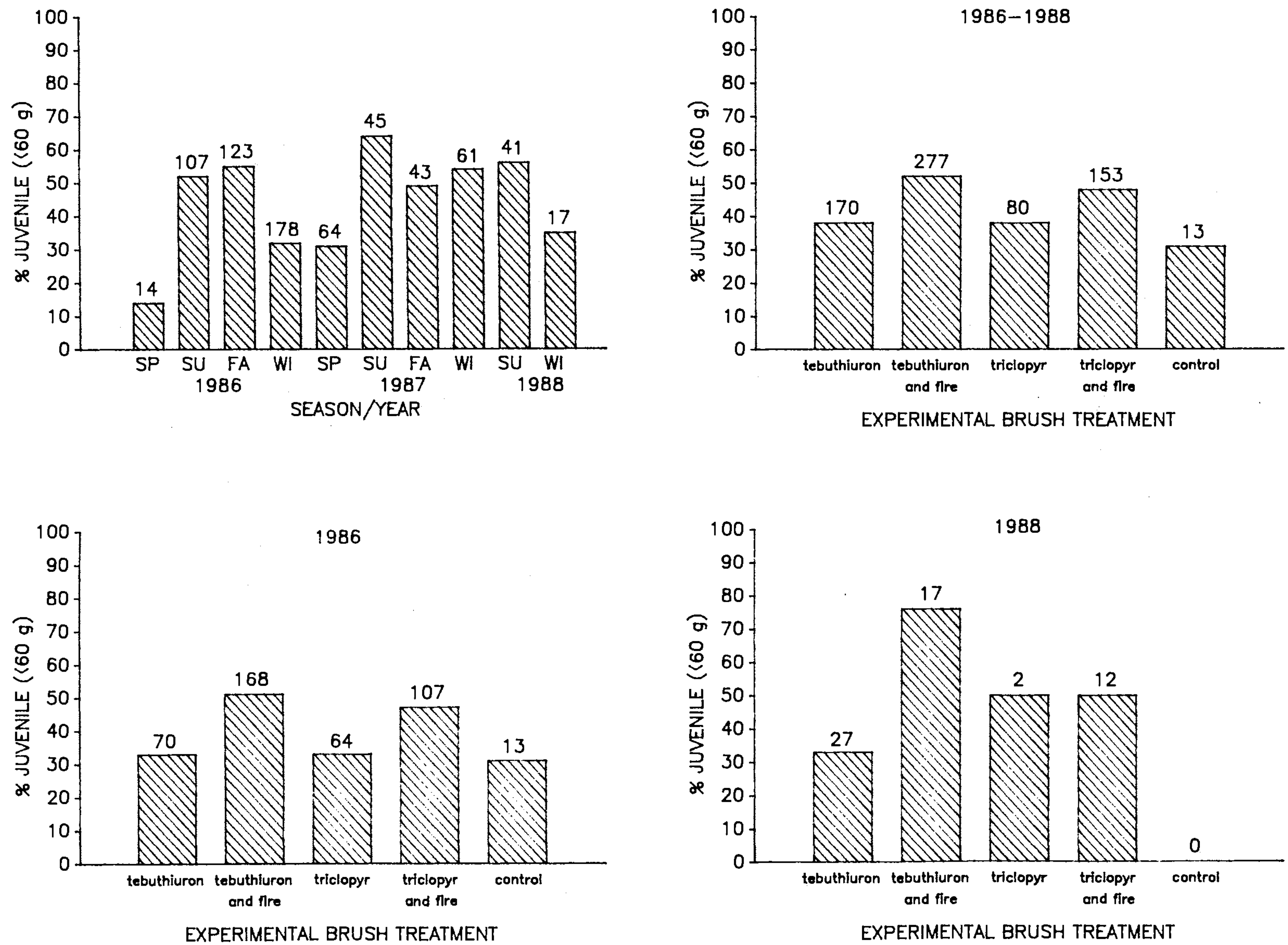
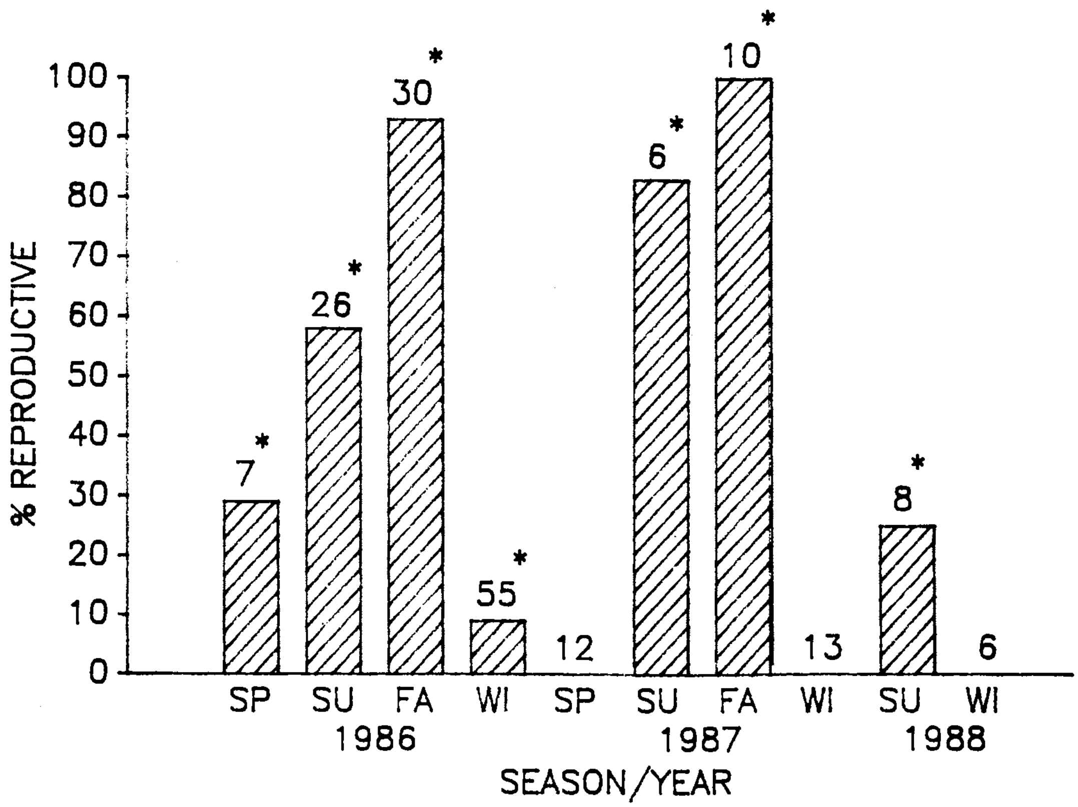

ANIMALS CAUGHT/100 TRAP-NIGHTS
0
1
2
3
4
5
6
7
8
9
10
TEB
TEB/FIRE
TRIC
TRIC/FIRE
CONTROL
S86
S86
F86
W86
S87
S87
F87
W87
S88
W88
SEASON/YEAR

Figure 2. Seasonal trends in percent juvenile cotton rats from spring 1986 to winter 1988 and differences among experimental brush treatments (years and seasons pooled) and in 1986 and 1988 (seasons pooled). Values above bars represent sample size (N).

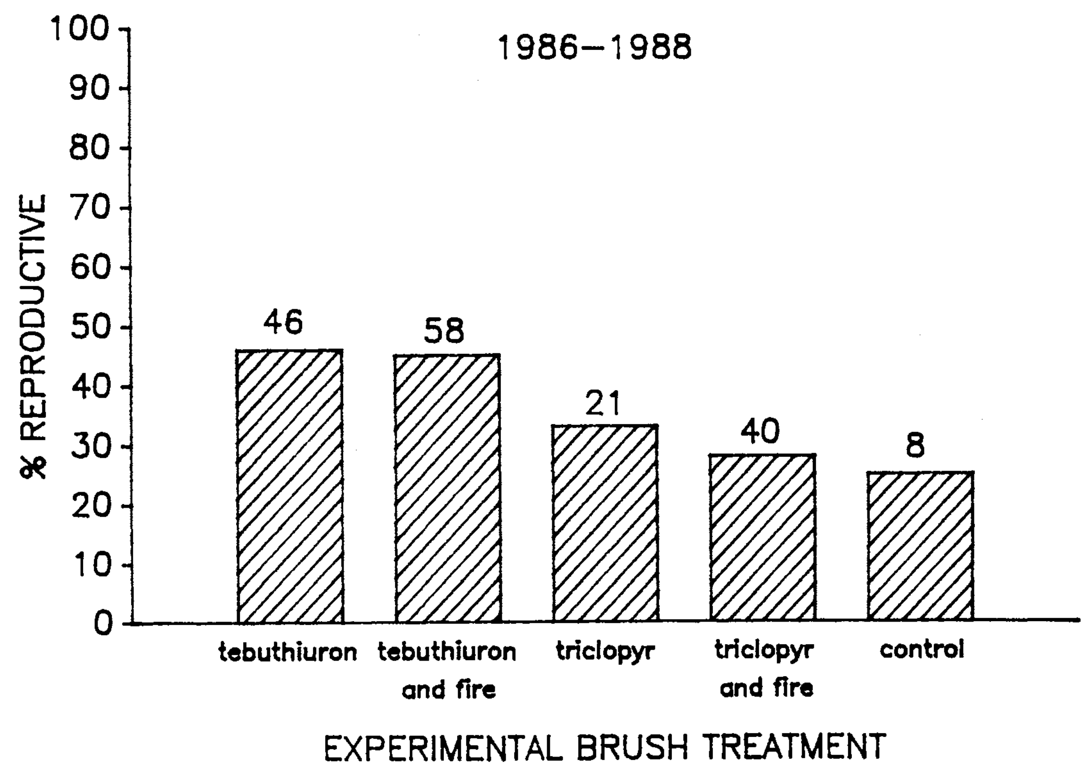


% JUVENILE (<60 g)
14
107
123
178
64
45
43
61
41
17
SP SU FA WI SP SU FA WI SU WI
1986
1987
1988
SEASON/YEAR
1986–1988
170
277
80
153
13
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT
1986
70
168
64
107
13
1988
27
17
2
12
0

Figure 3. Seasonal trends in percent reproductively active (pregnant or lactating) adult female cotton rats from spring 1986 to winter 1988 and differences among experimental brush treatments (years and seasons pooled). Values above bars represent sample size (N). Asterisks (*) above bars denote seasons in which pregnant females were caught.

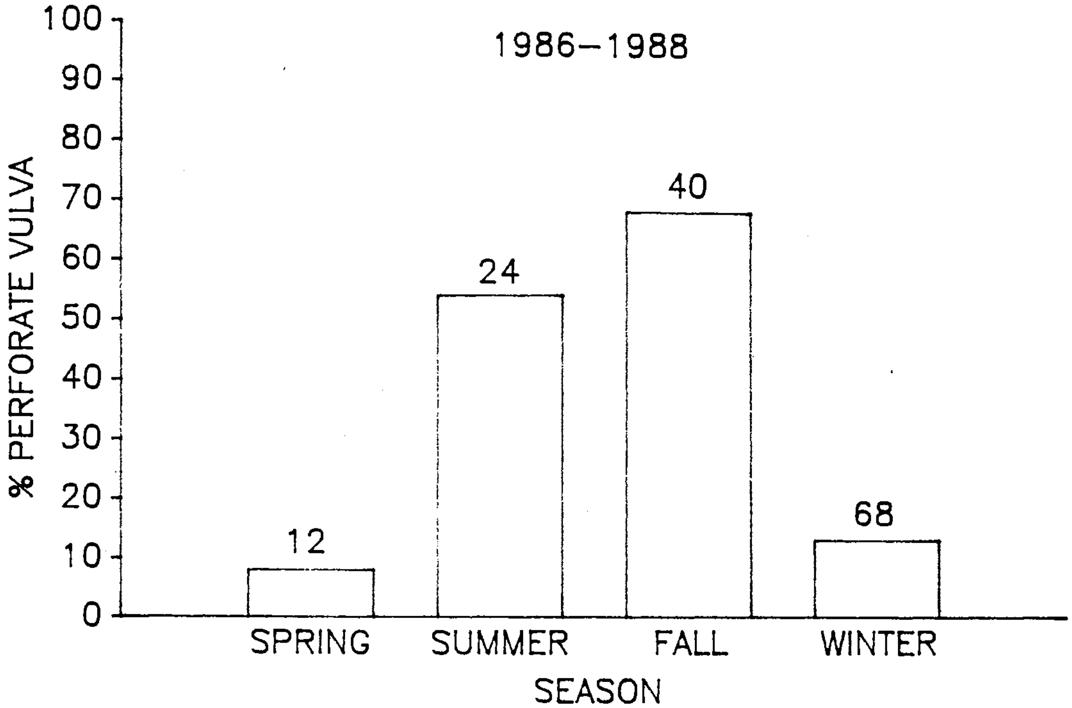


% REPRODUCTIVE
100
90
80
70
60
50
40
30
20
10
0
7 *
26 *
30 *
55 *
12
6 *
10 *
13
8 *
6
SP
SU
FA
WI
SP
SU
FA
WI
SU
WI
1986
1987
1988
SEASON/YEAR



% REPRODUCTIVE
100
90
80
70
60
50
40
30
20
10
0
1986–1988
46
58
21
40
8
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

Figure 4. Differences in percentage of adult female cotton rats with a perforate vulva among seasons (years pooled) and experimental brush treatments (years and seasons pooled). Values above bars represent sample size (N).


1986–1988
% PERFORATE VULVA
0
10
20
30
40
50
60
70
80
90
100
12
24
40
68
SPRING
SUMMER
FALL
WINTER
SEASON

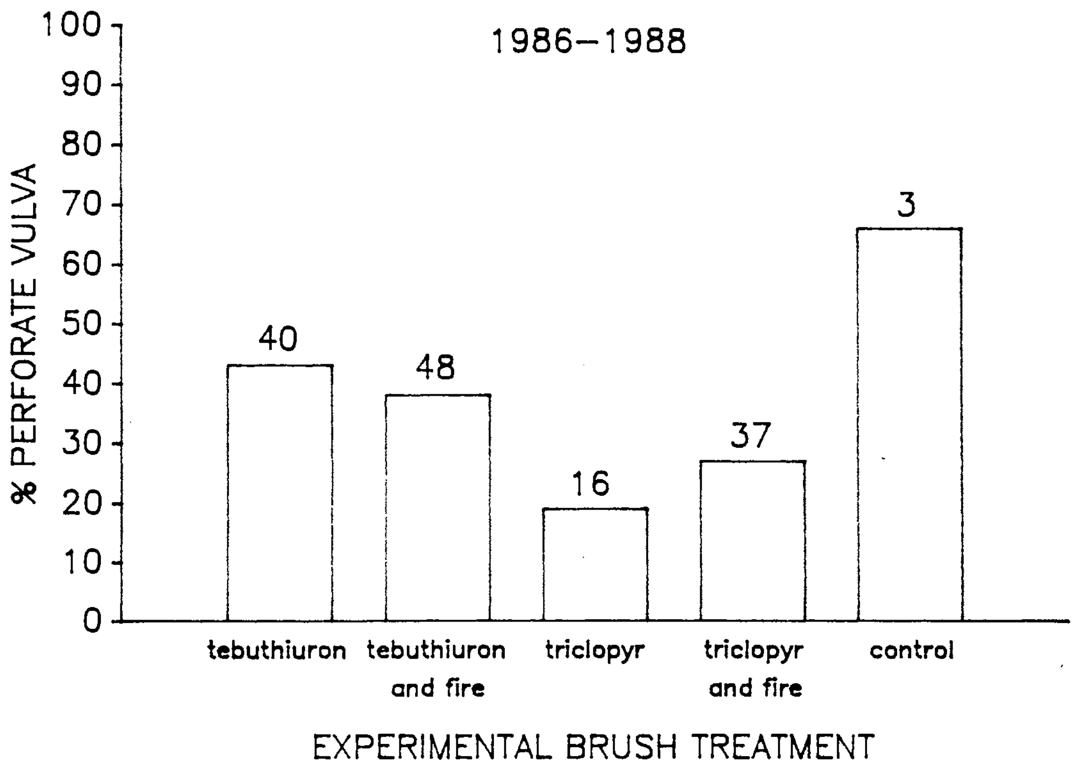
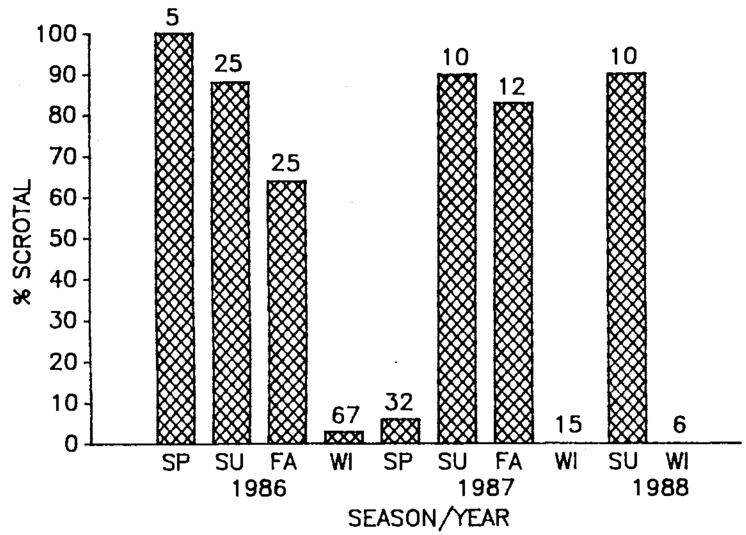
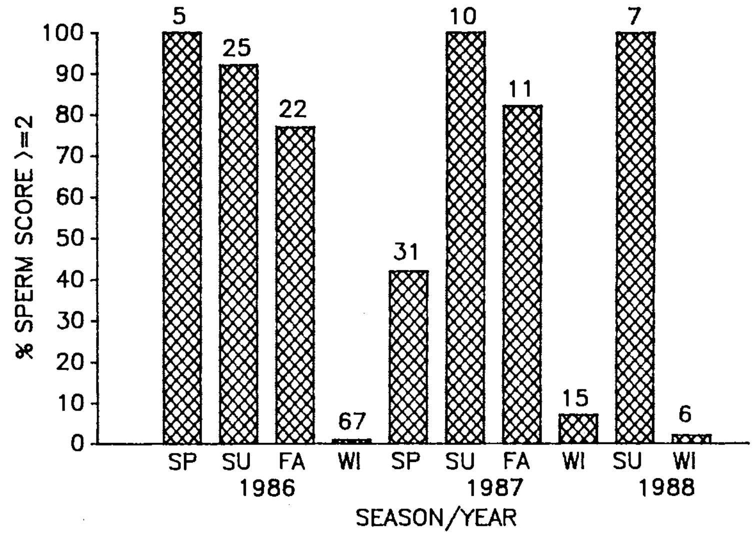

1986–1988
% PERFORATE VULVA
0
10
20
30
40
50
60
70
80
90
100
40
48
16
37
3
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

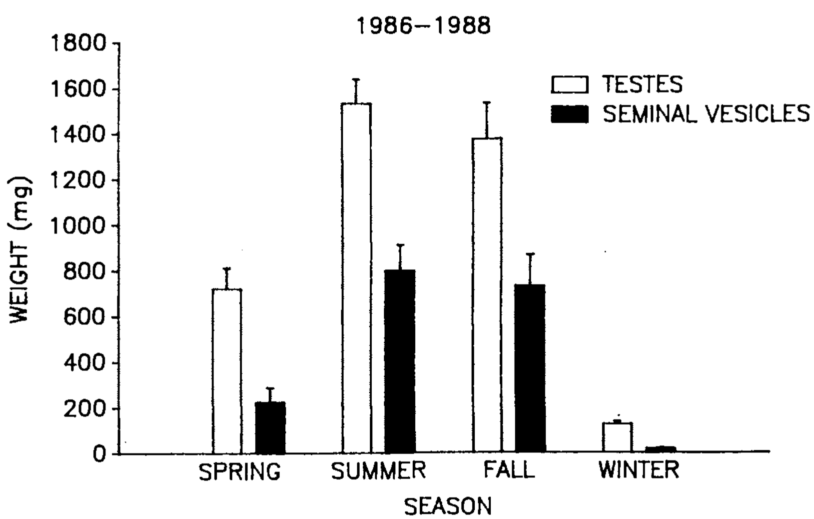
Figure 5. Trends in testes position and relative sperm abundance scores for adult male cotton rats from spring 1986 to winter 1988 and differences in mean testes and seminal vesicle gland weights among seasons (years pooled) and experimental brush treatments (years and seasons pooled). Values above bars represent sample size (N).



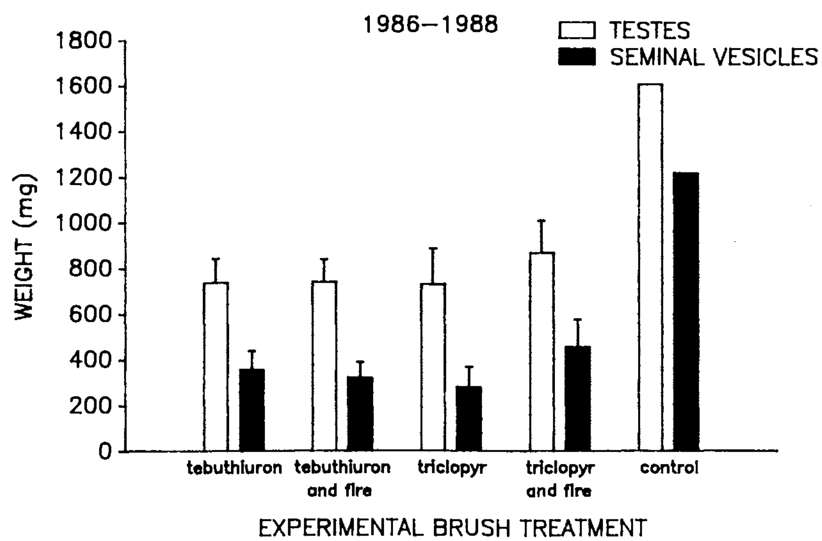
% SCROTAL
5
25
25
67
32
10
12
15
10
6
SP SU FA WI SP SU FA WI SU WI
1986 1987 1988
SEASON/YEAR



% SPERM SCORE >=2
5
25
22
67
31
10
11
15
7
6
SP SU FA WI SP SU FA WI SU WI
1986 1987 1988
SEASON/YEAR

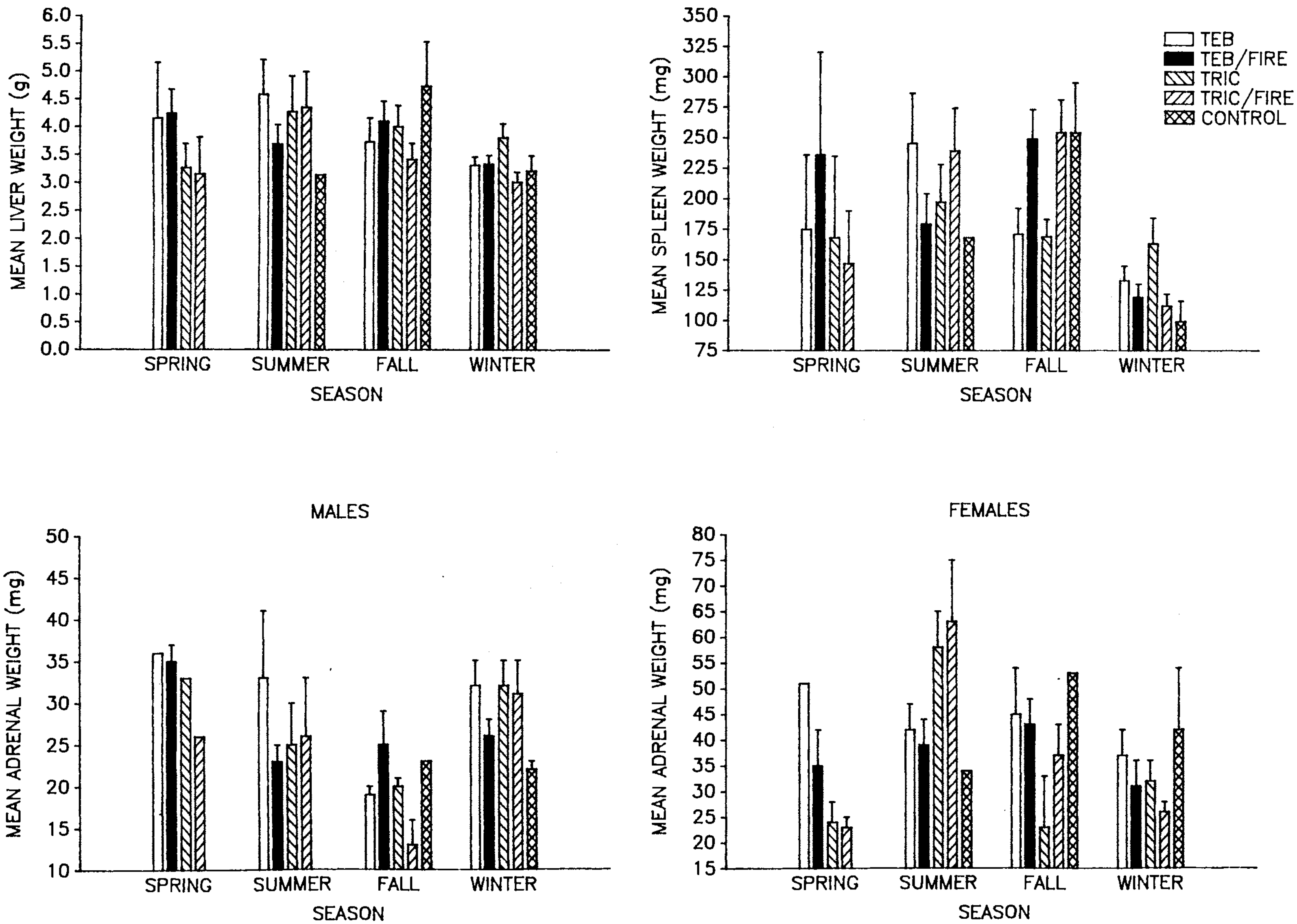


1986–1988
TESTES
SEMINAL VESICLES
WEIGHT (mg)
SPRING SUMMER FALL WINTER
SEASON



1986–1988
TESTES
SEMINAL VESICLES
WEIGHT (mg)
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

Figure 6. Mean weight (±SE) of liver and spleen (male and female combined) and paired adrenal glands (male and female seperate) from adult cotton rats caught in 1986.


MEAN LIVER WEIGHT (g)
MEAN SPLEEN WEIGHT (mg)
TEB
TEB/FIRE
TRIC
TRIC/FIRE
CONTROL
MALES
FEMALES
MEAN ADRENAL WEIGHT (mg)
MEAN ADRENAL WEIGHT (mg)
SPRING
SUMMER
FALL
WINTER
SEASON

CHAPTER IV

RESPONSES OF EASTERN WOODRAT (<u>NEOTOMA</u> <u>FLORIDANA</u>) POPULATIONS TO BRUSH MANAGEMENT ON CROSS TIMBERS RANGELAND IN OKLAHOMA

Abstract: I examined the influence of 5 experimental brush treatments on relative population density, reproduction, and body condition of eastern woodrat (*Neotoma floridana*) populations on cross timbers rangeland in Oklahoma. Experimental brush treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning, and untreated controls. A total of 333 eastern woodrats was collected from March 1986 through December 1988. Relative population density varied among seasons and experimental treatments. Summer peaks in density were observed each year but only on triclopyr treatments. Density was similar between populations on tebuthiuron treatments and controls. Reproductive activity of females varied among seasons, but not experimental treatments, with peaks in spring and fall 1986 and summer 1987. Percentage of males that were reproductively active, as evidenced by testes position and spermatogenesis, was less than expected in winter. Percentage of males with scrotal testes was greater than expected on herbicide treatments compared to controls. Mean body weights and condition scores varied among seasons being highest in fall and spring, but were not influenced by experimental treatments. Mean stomach content weight did not differ among seasons or experimental brush treatments.

Composition and structure of vegetation are two important habitat factors regulating the distribution of small mammal populations (Kaufman and Fleharty 1974, M'Closkey and Lajoie 1975, Austin and Urness 1976, Ormiston 1984, Scheibe 1985). Natural successional and man-induced (usually retrogressional) modifications of habitat that change vegetational composition and structure can be expected to have profound impacts on resident small mammal communities (Keith et al. 1959, Kirkland 1978, Borrecco et al. 1979, Santillo et al. 1989, Lawrence 1966, Buech et al. 1977, Kaufman et al. 1988).

The desire of livestock producers to use brush infested rangelands for grazing has led to widespread use of herbicides and fire as brush management tools. Range management techniques such as these usually initiate retrogression and can profoundly alter vegetation composition and structure (Scifres 1980). As composition and structure of vegetation changes, suitability of the habitat for some small mammal species could be altered. Demographic responses of small mammal communities to herbicides 2,4-D (Keith et al. 1959), 2,4,5-T (Kirkland 1978), atrazine (Borrecco et al. 1979), and glyphosate (Santillo et al. 1989), as well as prescribed burning (Lawrence 1966, Kaufman et al. 1988) and wildfires (Cook 1959, Buech et al. 1977) have been examined in a variety of ecosystems. Although herbicides are often followed by prescribed fire to suppress post-treatment resprouting of woody species, few studies (Senzota 1985) have examined effects of combinations of herbicide and prescribed fire on small mammal populations.

Two herbicides, tebuthiuron (N-[5-(1,1-dimethyl-ethyl)-1,3,4-thiadiazol-2 yl]-N,N'-dimethylurea), and triclopyr ([(3,5,6-trichloro-2-pyridinyl) oxy] acetic acid), are used for managing the hardwood overstory in the Cross Timbers of Oklahoma. Despite increased usage, relatively little is known about wildlife responses to habitat modifications that occur with tebuthiuron and triclopyr applications. The primary objectives of my study were to evaluate demographic, reproductive, and condition responses of eastern woodrat (*Neotoma floridana*) populations to tebuthiuron and triclopyr, used in combination with and without annual prescribed burning, in central Oklahoma on oak-dominated cross timbers vegetation. Although eastern woodrats are opportunistic and will inhabit a variety of rangelands, vegetative cover is of primary importance (Birney 1973).

METHODS

Study area.--This study was conducted on the Cross Timbers Experimental Range (CTER), located approximately 11 km southwest of Stillwater, Oklahoma. The CTER encompasses 648 ha of typical cross timbers rangeland composed of upland forest with interspersed grassland-cedar savannas. The CTER has a long land-use history of cultivation, crop abandonment, and livestock grazing that has resulted in a general decline in site potential and range condition (Ewing et al. 1984). Upland forest habitats are dominated by post oak (*Quercus stellata*) and black-jack oak (*Q. marilandica*) in the overstory and eastern redcedar (*Juniperus virginiana*), rough-leaf dogwood (*Cornus drummondii*), redbud (*Cercis canadensis*), American elm (*Ulmus americana*), and coralberry (*Symphoricarpos orbiculatus*) in the understory. Understory herbaceous dominants include little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), rosette panicgrass (*Panicum oligosanthes*), and western ragweed (*Ambrosia psilostachya*).

Experimental design.--The CTER is divided into 20 32.4-ha experimental pastures representing 4 replications of 5 experimental brush treatments in a randomized block design. Pastures were assigned to respective blocks according to their similarity in total woody canopy cover and soils. The 5 experimental treatments included: (1) tebuthiuron, a soil applied herbicide (Elanco Products Co., Division of Eli Lilly and Co., Indianapolis, Indiana 46285), applied aerially at 2.2 kg per ha in March 1983; (2) tebuthiuron (as with treatment #1) with annual prescribed burning beginning April 1985; (3) triclopyr, a foliage applied herbicide (Dow Chemical Co., Midland, Michigan 48674), applied aerially at 2.2 kg per ha in June 1983; (4) triclopyr (as with treatment #3) with annual prescribed burning beginning in April 1985; and (5) untreated control. All experimental pastures were fenced and moderately grazed by yearling cattle from April to September of each year.

Animal collection.--Eastern woodrat populations were censused seasonally (Mar, Jun, Sep, Dec) in 1986 and 1987 and biannually (Jun and Dec) in 1988 for a total of 10 sampling periods. For each sampling period, 2 replications of each experimental treatment were censused using removal trapping on a randomly placed 1.10-ha grid. Each grid consisted of eight 105 m transect lines with 15 m spacing between transect lines and 30 m spacing between grid points. Upland forest habitat was censused and trapping grids were relocated with each new sampling period so that no area within an experimental pasture was trapped more than once. I also alternated replications censused after every 2 successive sampling periods. Victor rat traps (32 each) were evenly distributed on each grid with placement restricted to within a 1-m radius of each grid point. A peanut butter and rolled oat mixture was used as bait. Each grid was trapped for 3 consecutive nights with daily removal of all captures and all woodrat nests on each grid were enumerated. Relative density was calculated on a catch/unit effort basis and expressed as the number of animals caught/100 trap-nights. A trap-night was defined as one rat trap set for a single 24-hour period. Catch/unit effort values were calculated for each treatment replication sampled and corrections were made for traps sprung (Nelson and Clark 1973).

Collected animals were returned to the laboratory and total, body, tail, and hindfoot lengths ($\pm$1 mm) and body weight ($\pm$0.1 g) determined. Animals $\geq$200.0 g were classified as adults and those $\leq$199.9 g were considered juveniles (Goertz 1970). Reproductive status of each male was assessed by recording testes position (scrotal, abdominal), epididymal sperm smear score, and weight of testes and seminal vesicle gland. The presence of spermatozoa in the epididymis was ascertained by cutting the caudal pole, extruding its contents, and smearing across a glass slide. Slides were examined microscopically, and relative abundance of sperm was assessed by assigning a numerical rank of 0 (none), 1 (trace), 2 (moderate), and 3 (abundant). Condition of the vulva of each female was recorded as perforate or imperforate. Females were classified as pregnant only when embryos were grossly visible upon necropsy. Embryos and uterine scars were enumerated when present. Data on the condition of the vulva and presence of uterine scars were not collected at the start of the study in spring 1986. Females were recorded as lactating if mammary tissue was conspicuous with hair-free areas surrounding nipples. Females were considered reproductively active when pregnant or lactating. Animal condition was assessed by examining weights ($\pm$0.1 mg) of liver, spleen, paired adrenal glands, and oven-dry stomach contents. Contents were removed from each stomach and dried to constant weight at 55 C. A general condition index was calculated for each animal as the proportion of body weight to body length.

Statistical Analyses.--Differences in age and sex ratios and male (testes position, sperm abundance scores) and female (reproductive status, vulva condition, presence of uterine scars) reproductive parameters among experimental brush treatments and seasons were analyzed using chi-square statistics (Koopmans 1981). Relative population density estimates were arcsine transformed (Sokal and Rohlf 1981), and differences among experimental brush treatments and seasons tested by analysis of variance (SAS 1985). Condition (body weight, organ and gland weights, condition score) and morphometric parameters were independently rank transformed prior to data analyses as a method to analyze non-normally distributed data (Conover and Iman 1981). Main and interactive effects of experimental brush treatment and season were examined by analysis of variance for the rank transformed data (Conover and Iman 1981). Specific contrasts were used in all analysis of variance procedures to compare differences between major experimental brush treatment components (tebuthiuron vs. triclopyr, burned vs. unburned, herbicide-treated vs. untreated controls).

RESULTS

Population characteristics.--A total of 333 eastern woodrats was captured over the 3-year study. Mean relative population densities (Fig. 1) differed significantly among seasons ($P < 0.001$) and experimental brush treatments ($P < 0.005$). Seasonal fluctuation in relative population density was similar among control and tebuthiuron-treated experimental pastures over the 3-year study. Populations in these experimental pastures were essentially stable where seasonal estimates of relative population density ranged from 0 to 7 animals captured/100 trap-nights but did not differ ($P > 0.100$). The amplitude of seasonal fluctuations in relative population density was considerably more pronounced ($P < 0.005$) for eastern woodrat populations inhabiting triclopyr-treated experimental pastures. These flucuations were characterized by prominant summer peaks, where relative population density ranged from 14.0 to 18.7 animals/100 trap-nights, followed by a large decline from summer to fall. Specific contrasts revealed that relative population densities of eastern woodrats inhabiting herbicide-treated pastures were significantly ($P < 0.004$) greater than untreated controls. Relative population density of eastern woodrats also was greater ($P < 0.001$) on pastures treated with triclopyr than tebuthiuron. There was no difference ($P > 0.100$) in relative population densities between burned and unburned experimental pastures.

Sex and age ratios (all years pooled) showed no significant (*P* > 0.100) differences among experimental brush treatments (Figs. 2 and 3). Although only 23 eastern woodrats were captured on untreated controls over the 3-year study, males tended to be greater than expected (X^2 = 3.1, 1 df, *P* < 0.100) on these pastures compared to herbicide treatments (Fig. 2). There was no significant difference (*P* > 0.100) in sex ratios among seasons. However, percentage of juveniles in eastern woodrat populations exhibited significant seasonal variation over the 3-year study (X^2 = 43.0, 3 df, *P* < 0.001). Percentage of juveniles was higher than expected in summer and lower than expected in winter compared to other seasons (Fig. 3).

Reproductive activity.--Since females were judged to be reproductively active only if embryos were grossly visible or lactation was evident, the number of reproductively active females may have been underestimated because of my inability to detect very early pregnancies. Adult female eastern woodrats were reproductively active throughout the study except in winter 1988 (Fig. 4). Distinct seasonal peaks of reproductive activity were evident (X^2 = 22.7, 3 df, *P* < 0.001), and all adult females captured in spring and fall 1986 and summer 1987 were reproductively active. Percent of adult females that were reproductively active showed no significant (*P* > 0.100) relationship to experimental brush treatments. A total of 9 pregnant eastern woodrats was captured, 8 of which came from triclopyr-treated pastures and 1 from a tebuthiuron treatment. Litter size ranged from 1 to 4 with a mean of 2.89 ± 0.26 (SE) fetuses/pregnant female. Pregnant eastern woodrats were captured at least once in all seasons except winter and all years except 1988 (Fig. 4).

Condition of the vulva (perforate, imperforate) by itself is not a reliable measure of the number of reproductively active females because it can reseal after copulation and perforate females may not always breed (David and Jarvis 1985). However, percentage of adult females with a perforate vulva differed ($\underline{X}^2$ = 10.1, 2 df, $\underline{P}$ < 0.010) among seasons (all years pooled) and was similar to observed trends in female reproductive activity (Fig. 5). Spring was not included in the chi-square analysis since only 2 adult females were collected in this season. The percentage of adult females with a perforate vulva was greater than expected in summer and fall compared to winter. Experimental brush treatment had no influence ($\underline{P}$ > 0.100) on percentage of adult females with a perforate vulva. Percent adult females with uterine scars was greater ($\underline{X}^2$ = 7.9, 2 df, $\underline{P}$ < 0.025) than expected in summer compared to fall and winter (Fig. 5), but did not differ ($\underline{P}$ > 0.100) among experimental brush treatments. However, percentage of adult females with uterine scars approached significantly ($\underline{X}^2$ = 2.9, 1 df, $\underline{P}$ < 0.100) greater levels on burned than unburned experimental treatments.

The seasonal reproductive pattern of adult male eastern woodrats, as determined by percent scrotal (Fig. 6), closely mirrored the pattern observed for adult females. However, the reproductive pattern of males, as indicated by the relative degree of spermatogenesis (Fig. 6), did not resemble the reproductive pattern observed for adult females. The percentage of adult males that were scrotal ($\underline{X}^2$ = 29.1, 3 df, $\underline{P}$ < 0.001) or had relative sperm abundance scores $\geq$ 2 ($\underline{X}^2$ = 8.4, 3 df, $\underline{P}$ < 0.050) in winter was less than expected compared to other seasons (all years pooled). Reproductive activity of adult males appeared to be influenced by experimental brush treatment. Pooled data for all 3-years indicated that the percentage of adult males with scrotal testes was greater ($\underline{X}^2$ = 4.6, 1 df, $\underline{P}$ < 0.050) than expected on herbicide-treated pastures compared to untreated controls (Fig. 6). However, percentage of adult males with relative sperm abundance scores $\geq$ 2 only approached significance ($\underline{X}^2$ = 3.1, 1 df, $\underline{P}$ < 0.100), being higher on herbicide-treated pastures compared to controls (Fig. 6).

Mean ranked testes (P < 0.003) and seminal vesicle gland ($\underline{P}$ < 0.001) weights (all years pooled) of adult male eastern woodrats varied significantly among seasons (Fig. 6). Mean testes weights were heaviest from spring to fall and lightest in winter, while seminal vesicle gland weights were heaviest in spring and lightest in winter. No differences ($\underline{P}$ > 0.100) were observed relative to testes or seminal vesicle gland weights among experimental brush treatments.

Condition.--Body weights and relative condition scores of adult eastern woodrats were used as relative indices of body condition. Body weight or relative condition score did not vary between sexes; therefore, male and female eastern woodrats were pooled for statistical analysis. Differences in mean adult body weight among seasons (all years pooled) approached significance ($\underline{P}$ < 0.053) with body weights in fall and spring being greater than winter (Fig. 7). Relative condition scores of adults also were significantly ($\underline{P}$ < 0.020) different among pooled seasons, being heaviest in fall and spring and lightest in winter. Experimental brush treatments had no influence ($\underline{P}$ > 0.100) on either mean body weights or relative condition scores of adult eastern woodrats. Dried stomach content weights did not differ ($\underline{P}$ > 0.100) among seasons or experimental brush treatments.

DISCUSSION

Overall, vegetation composition and structure were altered by experimental treatments. Pastures treated with herbicide produced more grasses and forbs than untreated controls (Engle et al. 1987). Although both herbicides killed most of the dominant overstory oak species, several woody understory species such as coralberry, American elm, and chittamwood (Bumelia lanuginosa) were controlled less by triclopyr than by tebuthiuron (Stritzke et al. 1987). Competition by woody understory species limited the amount of herbaceous plant production after treatment with triclopyr. Non-uniform burns in brushy upland sites were common because of inadequate accumulation of fine fuel and presence of cool season grasses (Engle et al. 1987). A mosaic pattern of burned and unburned areas occurred as a result.

Prescribed burning had no influence on eastern woodrat populations, indicating that burning did not alter any habitat parameters important to eastern woodrats. Burning on the CTER did not dramatically reduce understory brush (J. F. Stritzke, unpubl. data). Senzota (1985) monitored eastern woodrat populations on tebuthiuron-treated cross timbers rangeland in Texas that had been subjected to prescribed burning. Burning was apparently more successful at reducing brush in Senzota's (1985) study area, which resulted in significant reductions in the population density of eastern woodrats on burn treatments. Other information on woodrat responses to herbicide-induced habitat modifications are unavailable.

Herbicides had an obvious effect on relative population densities of eastern woodrats compared to untreated controls. However, density levels on triclopyr-treated pastures accounted for most of the observed differences between herbicide treatments and untreated controls. Differences in relative population density between tebuthiuron-treated and untreated control pastures were less apparent. Average peak relative density over the 3-year study on triclopyr treatments was 16.4 animals/100 trap-nights compared to 4.2 and 2.7 animals/100 trap-nights on tebuthiuron treatments and untreated controls, respectively.

It was difficult to determine if differences in relative population density were due to changes in vegetation composition, structure, or a combination of both. Average shrub stem densities for triclopyr treatments and controls were comparable in 1986, although both were nearly 4 times greater than tebuthiuron-treated pastures (J. F. Stritzke, unpubl. data). The preference that woodrats have for structurally diverse habitats is well documented (Rainey 1956, Goertz 1970, Cranford 1977). As one would expect, herbicide-killed trees produced an abundant supply of nest building material. The presence of adequate nest sites and building material is extremely important to eastern woodrat survival (Rainey 1956). Mean nest densities on trap grids in 1986 differed among triclopyr (8.2 ±1.3), tebuthiuron (5.7 ±1.2), and control (0.43 ±0.15 nests/ha) treatments. More nest building material was available on herbicide-treated pastures.

Average forb production on herbicide-treated pastures in 1986 was 2,900% greater than on untreated controls. Several important forages such as pokeweed (*Phytolacca americana*) and marestail (*Conyza canadensis*) were extremely abundant on herbicide treatments while absent on untreated controls (Engle et al. 1987). Although eastern woodrats are opportunistic and consume a wide variety of vegetation, the importance of any particular plant in the diet changes with location and plant species abundance (Wiley 1980). The flush in forb production following herbicide treatments may have provided an increase in food availability.

Although differences in relative population density were great, forb production from 1986 to 1988 on triclopyr treatments was only 5% less than on tebuthiuron-treated pastures (D. M. Engle, unpubl. data). This suggests eastern woodrats were selecting triclopyr-treated pastures for their greater structural complexity, especially with respect to understory cover. Eastern woodrats are commonly associated with habitats of thick understory brush (Goertz 1970) with security cover a primary factor in habitat selection. Cranford (1977) felt that although food resources were most abundant in preferred habitat, woodrats also have a strong affinity for dense undergrowth.

The abrupt increase in relative population density in summer on triclopyr-treated pastures would suggest greater recruitment compared to other treatment pastures. However, no differences were observed in the percent juveniles or percent reproductively active females among triclopyr- and tebuthiuron-treated pastures. It was interesting that 8 of the 9 pregnant females caught during the course of the study came from triclopyr-treated pastures. Differential reproduction likely occurred among treatments although 9 animals represents a small sample size. The only other indicators of increased reproductive activity on brush treatments were the percentage of females with visible uterine scars, and percentage of males with scrotal testes or relative sperm abundance scores ≥ 2. However, these parameters do not provide convincing evidence of greater recruitment on triclopyr-treated pastures.

A plausible explanation for the abrupt increase in relative population density on triclopyr-treated pastures in summer could be increased survival and dispersal of juveniles from other treatment pastures. Since I used removal trapping, differences in survival and dispersal of juveniles among populations could not be examined. However, triclopyr-treated pastures undoubtedly offered a higher degree of security cover than other treatments, possibly reducing predation rates (Rainey 1956). The availability of preferred habitats may have been considerably greater on triclopyr-treated pastures in summer as well, attracting dispersers from other experimental pastures. Eastern woodrats are known to travel out of existing home range sites, especially when reproductively active (Fitch and Rainey 1956) and have been recorded as moving 165m between capture points (Pearson 1952).

Goertz (1970) also noted that subadult eastern woodrats would move as much as 244m. Although dispersing juveniles will establish home ranges in close proximity to maternal ranges, occupation is usually temporary, serving as a refuge during an exploratory period before moving to an unoccupied but suitable area (Cranford 1977).

Increased survivability and dispersal are only two possible explanations and other factors may be involved in explaining the large differences in relative population densities among treatments in summers. The small numbers of adults collected in any given season may not have been sufficient for detecting statistical differences in recruitment and reproduction parameters among experimental treatments.

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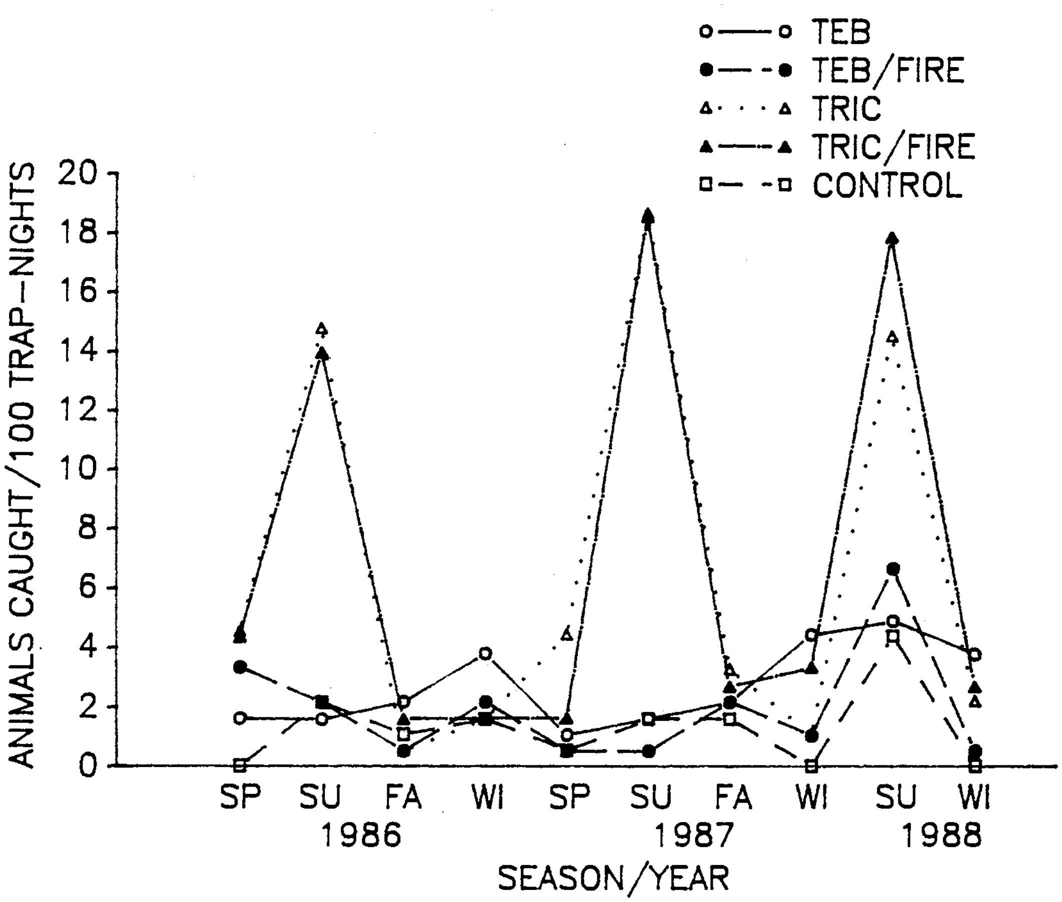
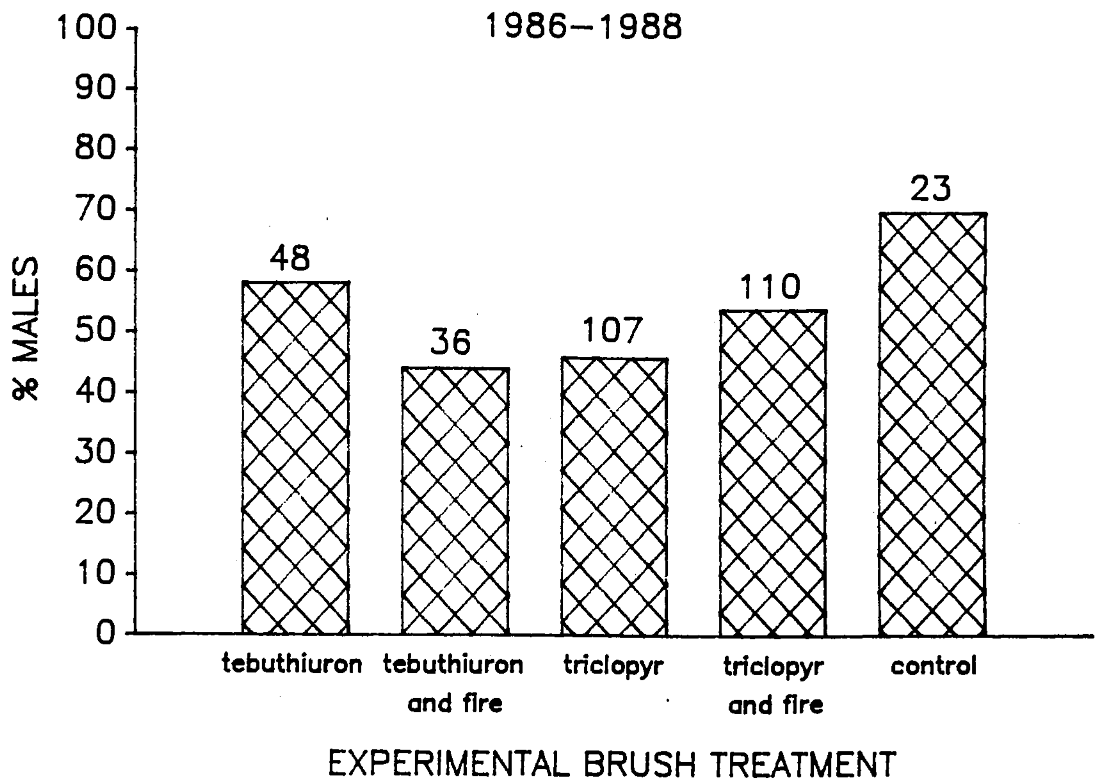
Figure 1. Total catch/unit effort of eastern woodrats on the 5 experimental brush treatments from spring 1986 to winter 1988.



TEB
TEB/FIRE
TRIC
TRIC/FIRE
CONTROL
ANIMALS CAUGHT/100 TRAP-NIGHTS
20
18
16
14
12
10
8
6
4
2
0
SP SU FA WI SP SU FA WI SU WI
1986
1987
1988
SEASON/YEAR

Figure 2. Differences in percent male eastern woodrats among experimental brush treatments (years and seasons pooled) and seasons (years pooled). Values above bars represent sample size (N).


1986–1988
% MALES
100
90
80
70
60
50
40
30
20
10
0
48
36
107
110
23
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

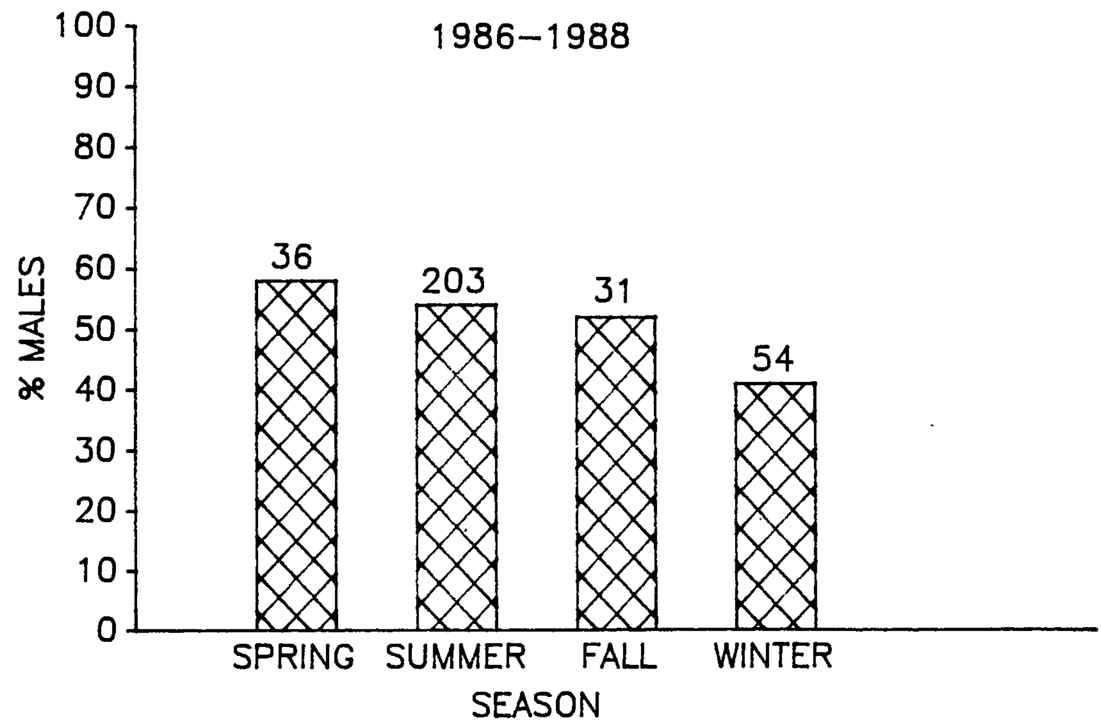
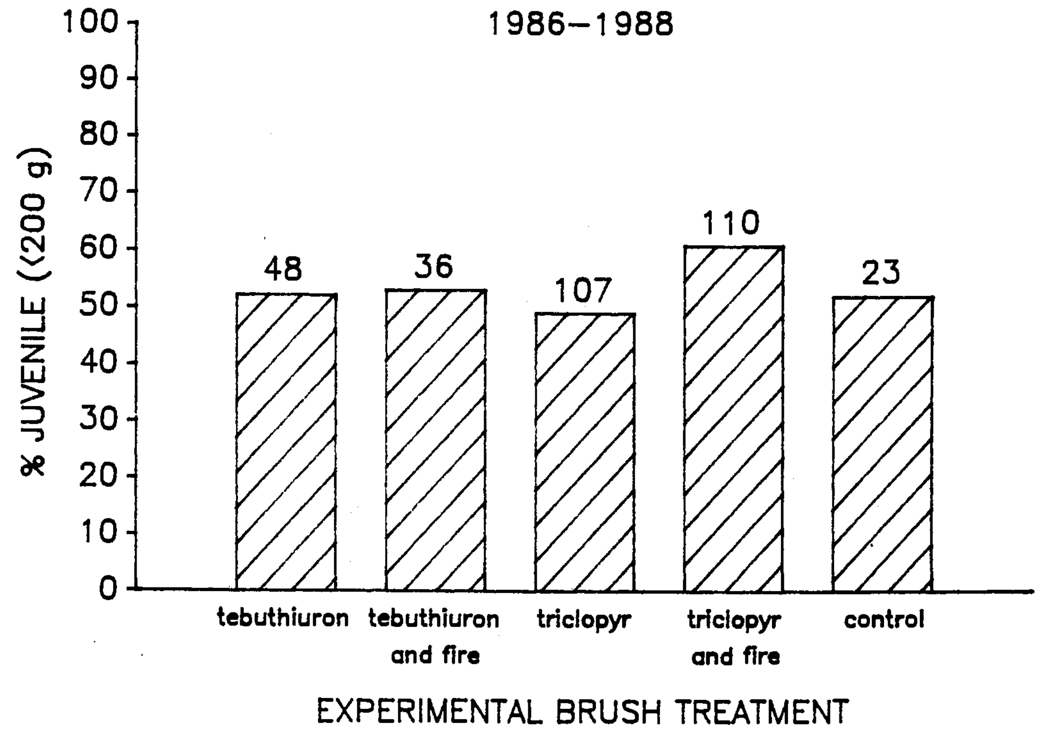
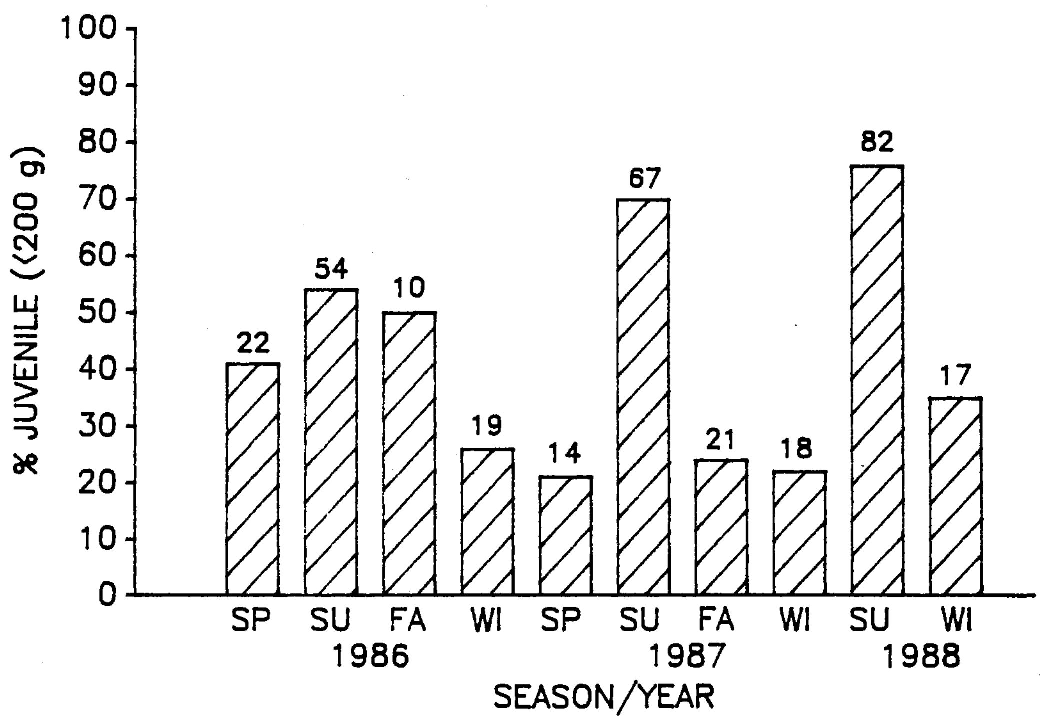

1986–1988
% MALES
100
90
80
70
60
50
40
30
20
10
0
36
203
31
54
SPRING
SUMMER
FALL
WINTER
SEASON

Figure 3. Differences in percent juvenile in populations of eastern woodrats among experimental brush treatments (years and seasons pooled) and seasonal trends from spring 1986 to winter 1988. Values above bars represent sample size (N).

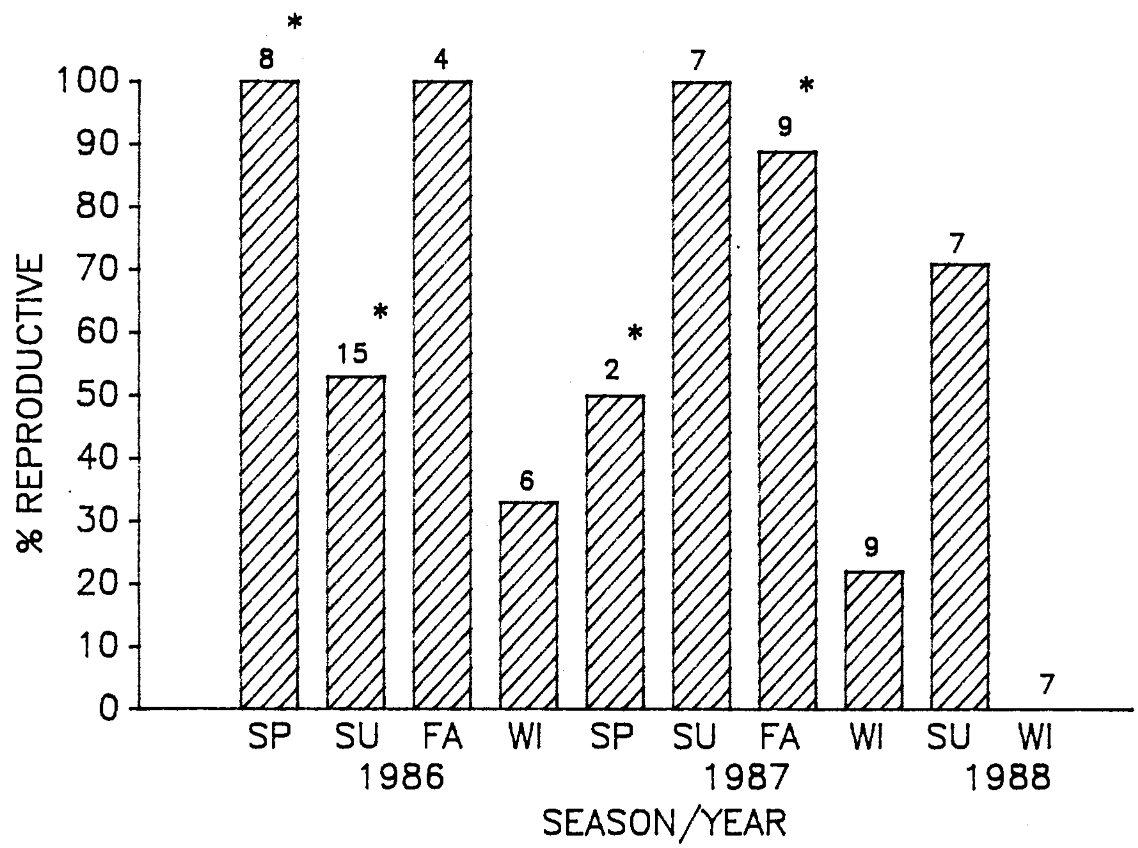


1986–1988
% JUVENILE (<200 g)
100
90
80
70
60
50
40
30
20
10
0
48
36
107
110
23
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT



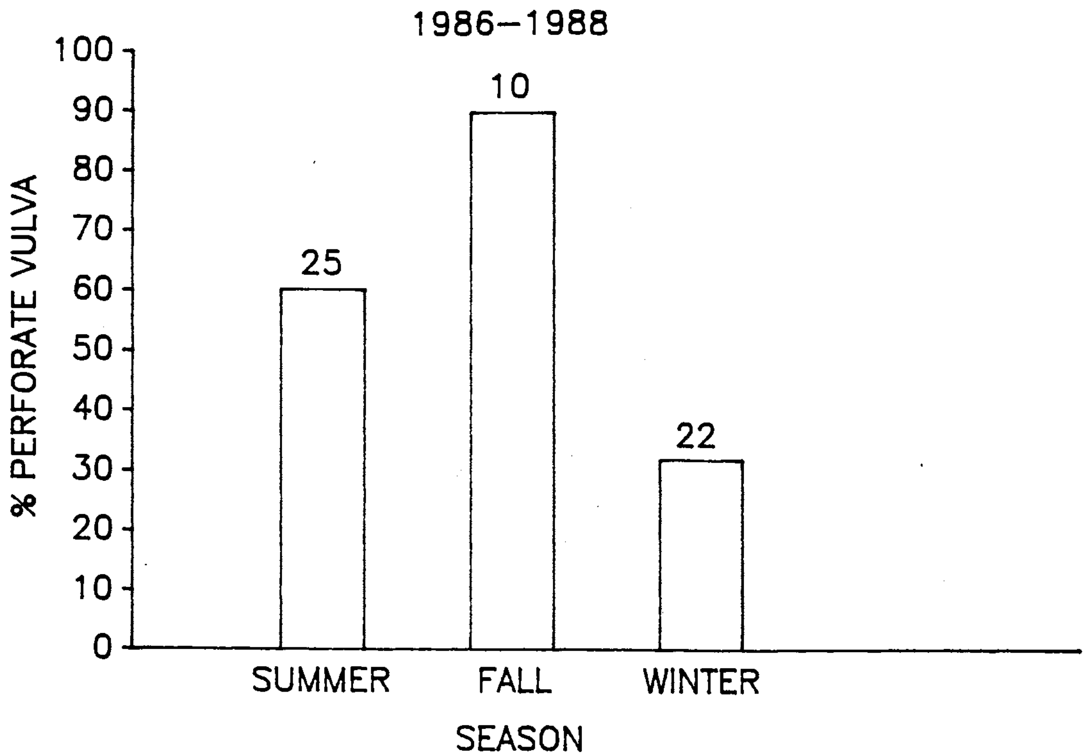
% JUVENILE (<200 g)
100
90
80
70
60
50
40
30
20
10
0
22
54
10
19
14
67
21
18
82
17
SP
SU
FA
WI
SP
SU
FA
WI
SU
WI
1986
1987
1988
SEASON/YEAR

Figure 4. Seasonal trends in percent reproductively active (pregnant or lactating) adult female eastern woodrats from spring 1986 to winter 1988. Values above bars represent sample size (N). Asterisks (*) above bars represent seasons in which pregnant females were caught.



% REPRODUCTIVE
100
90
80
70
60
50
40
30
20
10
0
8
*
15
*
4
6
2
*
7
9
*
9
7
7
SP
SU
FA
WI
SP
SU
FA
WI
SU
WI
1986
1987
1988
SEASON/YEAR

Figure 5. Differences in percent adult female eastern woodrats with a perforate vulva or uterine scars among seasons (years pooled). Spring data omitted because only 2 adult females were collected in spring. Values above bars represent sample size (N).


1986–1988
% PERFORATE VULVA
100
90
80
70
60
50
40
30
20
10
0
25
10
22
SUMMER
FALL
WINTER
SEASON

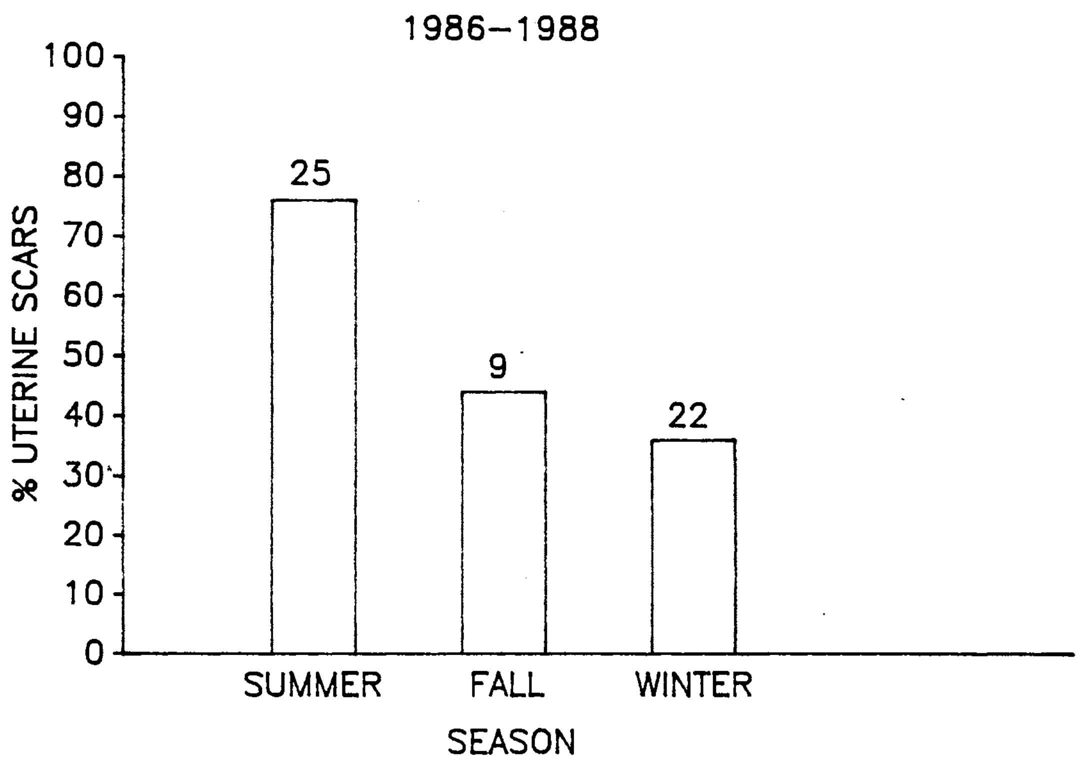
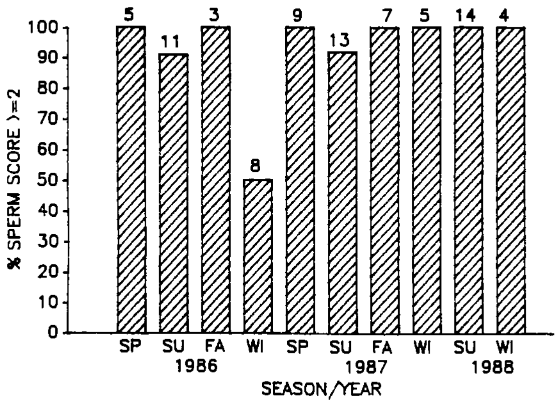
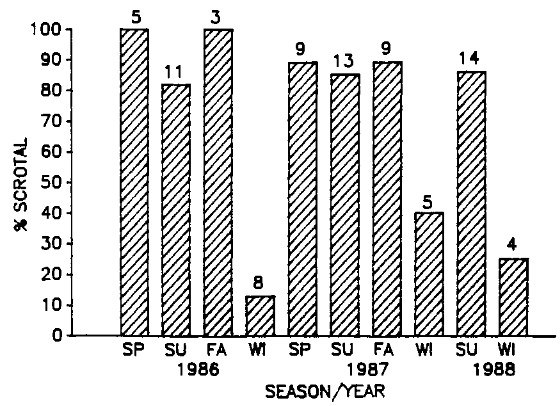
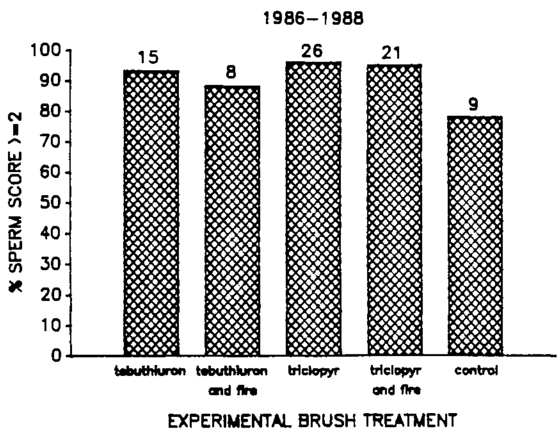
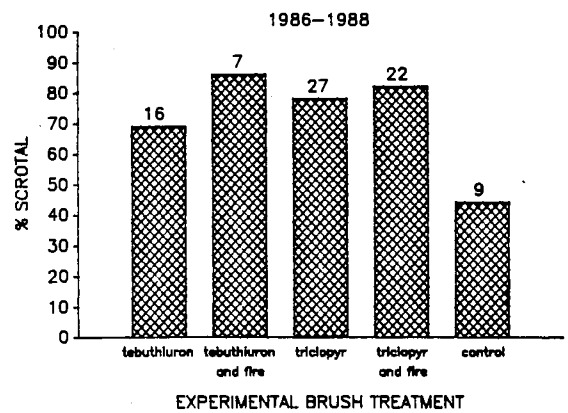

1986–1988
% UTERINE SCARS
100
90
80
70
60
50
40
30
20
10
0
25
9
22
SUMMER
FALL
WINTER
SEASON

Figure 6. Trends in relative sperm abundance scores and testes position in populations of eastern woodrats from spring 1986 to winter 1988 and differences among experimental brush treatments (seasons and years pooled). Also, differences in mean (+SE) testes and seminal vesicle gland weights among seasons (years pooled). Values above bars represent sample size (N).


% SPERM SCORE >=2
SP SU FA WI SP SU FA WI SU WI
1986 1987 1988
SEASON/YEAR
5 11 3 8 9 13 7 5 14 4


% SCROTAL
SP SU FA WI SP SU FA WI SU WI
1986 1987 1988
SEASON/YEAR
5 11 3 8 9 13 9 5 14 4


1986–1988
% SPERM SCORE >=2
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT
15 8 26 21 9


1986–1988
% SCROTAL
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT
16 7 27 22 9

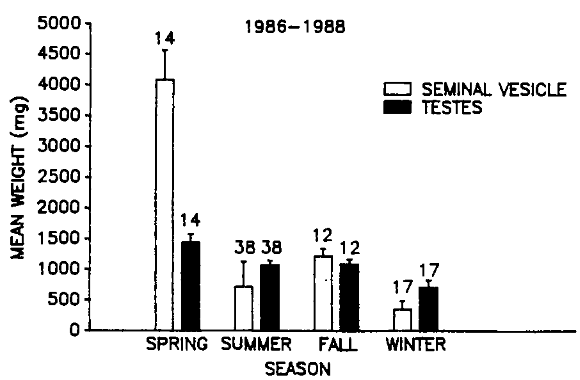
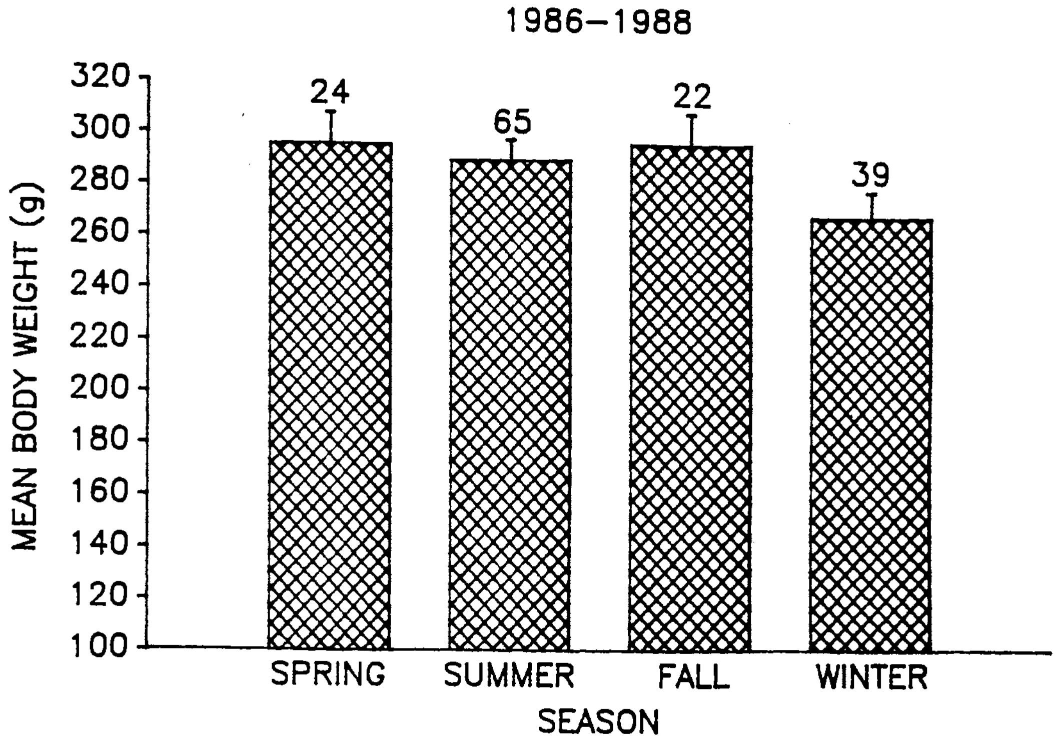
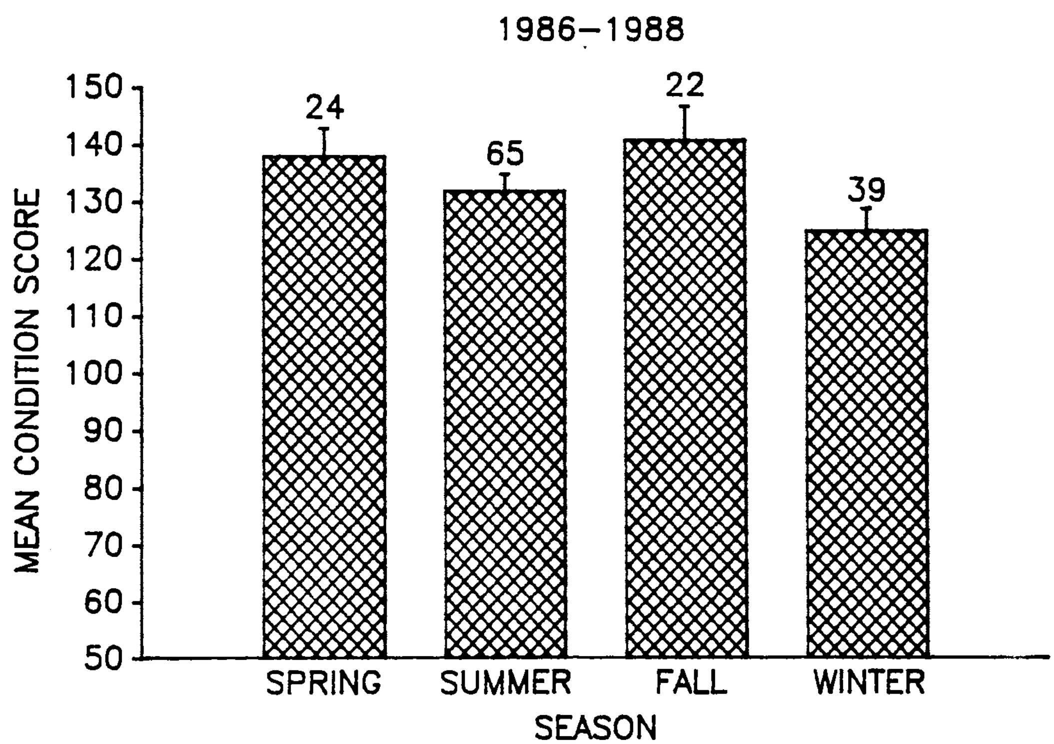

1986–1988
MEAN WEIGHT (mg)
SEMINAL VESICLE
TESTES
SPRING SUMMER FALL WINTER
SEASON
14 14 38 38 12 12 17 17

Figure 7. Differences in mean (±SE) body weight and condition score (body weight/body length x 100) in populations of adult eastern woodrats among seasons (years pooled). Values above bars represent sample size (N).


1986–1988
MEAN BODY WEIGHT (g)
320
300
280
260
240
220
200
180
160
140
120
100
24
65
22
39
SPRING
SUMMER
FALL
WINTER
SEASON


1986–1988
MEAN CONDITION SCORE
150
140
130
120
110
100
90
80
70
60
50
24
65
22
39
SPRING
SUMMER
FALL
WINTER
SEASON

CHAPTER V

EFFECT OF HERBICIDE AND PRESCRIBED BURNING ON FOOD HABITS OF EASTERN WOODRATS (*NEOTOMA FLORIDANA*) IN OKLAHOMA

Abstract: I examined composition of diets from eastern woodrats (*Neotoma floridana*) on Cross Timbers rangeland subjected to experimental brush manipulation. Treatments were tebuthiuron and triclopyr herbicides, applied with and without annual prescribed burning, and untreated controls. Microhistological techniques were used to estimate relative percent coverage of plant species in diets. A total of 23 plant species was found in diets from summer and winter samples. Eastern woodrats exhibited seasonal variation in diet selection. Summer diets consisted primarily of forbs and browse constituted most of the diet in winter. Pokeweed (*Phytolacca americana*) and eastern redcedar (*Juniperus virginiana*) comprised the greatest percentage of diets in summer and winter, respectively. Experimental brush treatment affected composition of the diet. Plant species richness and diversity was highest in diets in summer from triclopyr-treated pastures. Forbs occurred at greater percentages in diets from herbicide-treated and burned pastures compared to control and unburned pastures, respectively. Browse species comprised a greater percentage of diets from triclopyr treatments compared to tebuthiuron. Overlap of plant species in summer diets was more divergent than those from winter. In summer, composition of plant species in diets from controls overlapped 21.7% with diets form herbicide treatments. Minimum overlap of diets in winter was 88.2%. Crude protein content was highest in diets from tebuthiuron treatments in summer.

The Cross Timbers ecosystem accounts for nearly 8 million ha of rangeland in Oklahoma and surrounding states. Typically, this rangeland is of low quality and is primarily used for livestock production. Although the Cross Timbers is composed of a mosaic of upland oak forests with interspersed tallgrass prairie, dense brushy vegetation is characteristic of the forested areas and usually prohibits growth of most herbaceous plants (Ewing et al. 1984). The desire of livestock producers to more effeciently utilize these brushy areas has led to increased use of herbicides and prescribed burning as management tools. Such range improvement techniques can produce dramatic changes in vegetative structure and composition, usually initiating retrogression of the plant community (Scifres 1980). As composition of the plant community changes, availability of forages once utilized by resident small mammals could be altered, thereby causing a shift in diet selection. Eastern woodrats (Neotoma floridana) occupy a wide variety of habitats (Rainey 1956) but availability of cover and nest sites appear to determine distribution (Birney 1973). In the oak-dominated forests of central Oklahoma, eastern woodrats strongly associate with upland forests and dry ravines (Goertz 1970). Woody vegetation comprises a major component of the eastern woodrat diet, as indicated by studies of stomach contents (Strecker 1929, Murphy 1952, Cudmore 1983) and food caches (Goodpastor and Hoffmeister 1952, Rainey 1956). However, there appears to be a large amount of variability in food preferences among populations of eastern woodrats from different habitats (Wiley 1980).

Two recently developed herbicides, tebuthiuron (N-[5-(1,1-dimethyl-ethyl)-1,3,4-thiadiazol-2 yl]-N,N'dimethylurea) and triclopyr ([(3,5,6-trichloro-2-pyridinyl) oxy] acetic acid), have become popular for controlling brushy vegetation in the Cross Timbers region of central Oklahoma. Although demographic responses of small mammal populations to herbicide (Keith etal.1959, Kirkland 1978, Borrecco et al. 1979, Santillo et al. 1989) and prescribed burning (Lawrence 1966, Kaufman et al. 1988) have been examined in several ecosystems, dietary changes (Keith et al. 1959, Johnson 1964) have received less attention. The objective of this study was to evaluate how diet composition of eastern woodrats change in response to herbicide treatment and prescribed burning, both of which change composition of the plant community.

METHODS

Study area.--This study was conducted on the Cross Timbers Experimental Range (CTER) located approximately 11 km southwest of Stillwater, Oklahoma. The CTER encompases 648 ha of typical cross timbers rangeland composed of upland forest and interspersed grassland-cedar savannas. Upland forests are dominated by post oak (*Quercus stellata*) and black-jack oak (*Q. marilandica*) in the overstory and eastern redcedar (*Juniperus virginiana*), rough-leaf dogwood (*Cornus drummondii*), redbud (*Cercis canadensis*), American elm (*Ulmus americana*), and coralberry (*Symphoricarpos orbiculatus*) in the understory. Dominant herbaceous plants in the understory are little bluestem (*Schizachyrium scoparium*), indiangrass (*Sorghastrum nutans*), rosette panic grass (*Panicum oligosanthes*), and western ragweed (*Ambrosia psilostachya*).

Experimental design.--The CTER is divided into 20 32.4-ha experimental pastures representing 4 replications of 5 experimental brush control treatments in a randomized block design. Pastures were assigned to respective replications according to their similarity in total woody canopy cover and soils. The 5 experimental treatments included: (1) tebuthiuron, a soil applied herbicide (Elanco Products Co., Division of Eli Lilly and Co., Indianapolis, Ind.), applied aerially at 2.2 kg/ha in March 1983; (2) tebuthiuron (as with treatment #1) with annual prescribed burning beginning April 1985; (3) triclopyr, a foliage applied herbicide (Dow Chemical Co., Midland, Mich.), applied aerially at 2.2 kg/ha in June 1983; (4) triclopyr (as with treatment #3) with annual prescribed burning beginning in April 1985; and (5) untreated control. All experimental pastures were fenced and moderately grazed by yearling cattle from April to September of each year.

Animal collection.--Eastern woodrats were collected in June (summer) and December (winter) 1986 for dietary comparisons among treatments at seasonal extremes. In each sampling period, 2 replications of the 5 experimental treatments were sampled using standard Victor rat traps (32 each) on a 1.1 ha grid. Grids consisted of 8 parallel staggered transect lines (each 90 m long) with 15 m spacing between lines and 30 m spacing between trap stations. All trapping grids were randomly placed on upland forest sites and were moved to a new location in winter. Collected animals were returned to the laboratory, stomach contents removed and dried to a constant weight at 55 C, and stored in air-tight plastic bags until they could be processed.

Diet determination.--Reference plants of the dominant shrub, forb, and grass components of the 5 experimental brush treatments were collected in summer and winter 1986. Permanant microscopic slides of reference plants and stomach contents were prepared according to Davitt and Nelson (1980). If volume of stomach contents was deficient, stomach contents were composited (Jenks et al. 1989) by experimental brush treatment to obtain an adequate volume of sample. Only stomach contents obtained from woodrats captured in June 1986 had to be composited.

For each individual or composite sample, plant fragments on each of 3 slides were examined by randomly transversing the slide until 25 identifiable plant fragments/slide were observed. Plant fragments nearest to the center of the field of view were quantified at 100X by counting 0.25 mm2 sections of a 10 X 10 mm ocular grid. Relative percent cover (Kincaid and Cameron 1982) was calculated as the total area covered by a plant species divided by the total area surveyed. Plant fragments were identified to species when possible. However, if a plant fragment had insufficient characteristics for specific or generic identification, it was classified as either an unknown dicot or monocot.

Diet analysis.--Plant species were considered major components of the diet if they occurred in diets from all experimental treatments in either season. Plant species that comprised >10% of the diet but did not occur in diets from all experimental brush treatments were considered minor components of the diet. Forb and browse classes were used for analysis. Analysis of variance (SAS 1985) was used to test for differences among experimental brush treatments and seasons in the relative percent cover of major and minor plant species and forb and browse classes. All relative percent coverage estimates were arcsine transformed (Sokal and Rohlf 1981) prior to analysis. Specific contrasts were used to compare differences between major brush treatment components (tebuthiuron vs. triclopyr, burned vs. unburned, herbicide-treated vs. untreated controls). Multivariate analysis of variance (SAS 1985) was used to examine combined botanical composition of diets among experimental brush treatments and seasons. Only major dietary components were used in multivariate analysis. A significance level of $P \leq 0.05$ was used in all tests. Species richness was defined as the total number of different plant species in the diet. Diversity of diet was calculated by the Shannon-Weaver function (Shannon and Weaver 1949). Horn's (1966) similarity index was used in a cluster analysis to estimate similarity of plant species composition in diets from the 5 experimental brush treatments.

Weighted crude protein content of diets from all experimental brush treatments in both seasons were estimated (Westoby 1974). Plant species that comprised >85% of the total composition of the diet were used to estimate crude protein content of the diet. Crude protein values used in the calculations were derived from Short et al. (1975), McCullough and Ullrey (1985), O'Halloran et al. (1987), and Bogle et al. (1989). Crude protein value of ox-eye daisy (_Chrysanthemum_ leucanthemum) was unavailable, so black-eyed susan (Rudbeckia hirta) was used as a substitute.

RESULTS

Diet characteristics.--A total of 23 different plant species was identified in diets of eastern woodrats in summer and winter (Table 1). In summer, species richness was highest (12) in diets of eastern woodrats caught on triclopyr-treated pastures and lowest (7) on burned tebuthiuron treatments. Species richness of eastern woodrat diets in winter was less than summer and was highest on tebuthiuron-treated pastures (6) and lowest on controls (4) (Table 2). Diversity of plant species in eastern woodrat diets ranged from 1.0 to 2.7 in summer and 0.2 to 1.4 in winter (Table 2). In summer, diet similarity was highest between burned and unburned tebuthiuron-treated pastures (Fig. 1). Diets of eastern woodrats from herbicide-treated pastures were dissimilar to those from untreated controls. Composition of diets of eastern woodrats were similar among all experimental brush treatments in winter.

Prominant dietary components.--Six plant species comprised major components of diets of eastern woodrats: pokeweed (Phytolacca americana),eatern redcedar, elm (Ulmus sp.), tick clover (Desmodium sp.), western ragweed, and potentilla (Potentilla sp.) (Table 3).

The relative percent coverage of the major plants in the diet of eastern woodrats varied among seasons. Pokeweed, elm, tick clover (P < 0.001), and western ragweed (P < 0.012) comprised greater percentages of diets in summer compared to winter. Tick clover was found exclusively in summer diets, but pokeweed, elm, and western ragweed occurred in trace amounts in some winter diets. Eastern redcedar (P < 0.001) and potentilla (P < 0.003) comprised a greater percentage of diets in winter compared to summer. Both eastern redcedar and potentilla occurred at relatively low (<3.9%) levels in summer diets.

Percent coverage of pokeweed and elm in diets was significantly (P < 0.001) influenced by experimental brush treatment, and there was a significant (P < 0.001) treatment by season interaction. Specific contrasts showed that pokeweed comprised a greater portion of diets of eastern woodrats caught on herbicide-treated (P < 0.001) and burned (P < 0.045) pastures compared to control and unburned pastures, respectively. Elm comprised a greater portion of diets of eastern woodrats caught on triclopyr (P < 0.009) and unburned (P < 0.003) treatments compared to tebuthiuron-treated and burned pastures, respectively. Percent coverage of tick clover and potentilla in diets of eastern woodrats caught on herbicide-treated pastures approached significantly greater (P < 0.100) levels than those from untreated controls. Relative percent coverage of eastern redcedar and western ragweed were not influenced (P > 0.100) by experimental brush treatments.

Two minor components of the diet, fungi and grape (Vitis sp.), were analyzed in addition to the major diet items (Table 3). Percent coverage of fungi and grape in the diet did not differ (P > 0.100) among seasons or experimental brush treatments. However, specific contrasts indicated that percentage of fungi in the diet approached significantly

($P < 0.100$) greater levels on untreated controls compared to herbicide-treated pastures.

Analysis of relative percent coverage of forb and browse in diets of eastern woodrats showed significant ($P < 0.001$) seasonal variation (Fig. 2). Forbs comprised a greater portion of diets in summer compared to winter, but the reverse was true for browse. Percent coverage of forbs in diets of eastern woodrat also varied significantly ($P < 0.001$) among experimental brush treatments (Fig. 2). Specific contrasts revealed a higher percentage of forbs in diets on herbicide ($P < 0.001$) and burned ($P < 0.024$) treatments compared to untreated controls and unburned treatments, respectively. Percent coverage of browse in diets of eastern woodrats was significantly ($P < 0.013$) greater on pastures treated with triclopyr compared to tebuthuron.

Multivariate analysis of variance showed significant season ($P < 0.001$) and treatment ($P < 0.001$) differences in botanical composition of the major plant species in diets. Also, the effect of experimental brush treatment was significantly ($P < 0.001$) influenced by season. The influence of herbicide and prescribed burning had obvious effects on the percentage of major plant species that occurred in diets. Major plant species composition of diets differed significantly ($P < 0.001$) between untreated controls and herbicide-treated pastures. In addition, composition of diets were significantly different between tebuthiuron- and triclopyr-treated pastures ($P < 0.003$), and burned and unburned treatments ($P < 0.002$).

Diet quality.--Overall, estimated crude protein content of diets was lower in winter than summer (Fig. 3). Crude protein content of the diet was positively influenced by the percentage of forbs in the diet. Crude protein content of diets in summer was highest on tebuthiuron-treated pastures compared to other treatments (Fig. 3). Prescribed burning appeared to influence crude protein content of diets on tebuthiuron treatments but not on triclopyr treatments. No apparent differences were observed in crude protein content of diets among the 5 experimental brush treatments in winter.

DISCUSSION

Herbicide application and prescribed burning affected vegetation composition on the CTER (Engle et al. 1987). Forb standing crop was 5.9% greater in 1986 on pastures treated with tebuthiuron compared to triclopyr. In addition, average forb standing crop was 250% and 35% greater on burned tebuthiuron and triclopyr treatments, respectively, compared to unburned treatments in 1986. Overall, forb production was 2,900% greater on herbicide-treated pastures compared to controls (Engle et al. 1987). Mean stem density below 1 m of browse species was similar on triclopyr-treated and untreated controls although average stem density on triclopyr-treated and control pastures was 290% greater than on tebuthiuron-treated pastures (J. F. Stritzke, unpubl. data). Prescribed burning did not affect stem density. Eastern woodrats appear to utilize browse as their primary diet item, and consumption of various plant species appears to be related to availability of plant types (Rainey 1956). Our data suggests that diet composition is closely related to availability of various plant species in each experimental brush treatment.

Species richness was higher in diets of eastern woodrats from triclopyr-treated pastures in summer, which resulted from a higher number of browse species in those diets. Stem density of browse species was higher on triclopyr-treated pastures compared to tebuthiuron treatments which suggested that eastern woodrats utilized available browse in addition to forbs. Lower diversity of plant species in summer diets from burned tebuthiuron treatments seems attributable to increased selectivity of pokeweed. Average standing crop of pokeweed was 99% higher on burned tebuthiuron treatments than on other treatments (Engle et al. 1987). Eastern woodrats on triclopyr-treated pastures in winter relied less on eastern redcedar as their primary food source and supplemented their diet with fungi. Low diversity of plant species in winter diets from controls was directly related to an almost complete reliance on eastern redcedar as a food source. This suggests that eastern redcedar is the only abundant food on untreated controls. The relatively low production of forbs on control pastures had a strong influence on the dissimilarity among diets from herbicide treatments and controls. However, after forb production ended in winter, diets among experimental brush treatments were quite similar.

It is interesting that potentilla was used more in winter than summer. Potentilla is not an evergreen plant and therefore, woodrats must be caching it prior to winter. Selection of potentilla may be related to a combination of nutrient quality and an ability to withstand desiccation. Rainey (1956) noted that green vegetation in Kansas could over-winter in woodrat nests without severe desiccation. The presence of other forbs in woodrat diets must be attributable to caching as well. Utilization of eastern redcedar in winter as the primary component in diets is understandable because it was the most abundant green vegetation in winter. Cudmore (1983) also noted that eastern redcedar was one of the primary diet items in eastern woodrats caught in winter.

Overall, utilization of forbs appeared to be related to forb production on experimental treatments. For example, forb production was higher on herbicide and burned treatments and in both cases, percentage of forbs in diets was highest on these treatments. Specifically, pokeweed was more abundant in woodrat diets from herbicide treatments compared to controls which agrees with vegetation data from CTER (Engle et al. 1987). Pokeweed occurred on all herbicide-treated pastures but did not occur in samples from controls. One exception, however, was that pokeweed occurred in greater percentages in diets form burned treatments compared to unburned although the average frequency of occurrence of pokeweed was 24% greater on unburned treatments (Engle et al. 1987). Therefore, even though pokeweed was used rather extensively, it was not always used in direct relation to its occurrence on all treatments. Data on abundance of tick clover and potentilla are unavailable and conclusions regarding utilization vs. occurrence cannot be made. However, their percentage in the diet approached significantly greater levels on herbicide-treated pastures compared to controls.

Browse, like forbs, typically occurred in higher percentages in diets of animals from experimental treatments with abundant browse. For instance, browse was found in higher percentages in diets from triclopyr treatments compared to tebuthiuron treatments. In addition, elm occupied a higher percent of diets from triclopyr and unburned treatments compared to tebuthiuron and burned. Stem density of elm under 1 m was 1,070% greater on triclopyr-treated compared to tebuthiuron-treated pastures in 1986 (J. F. Stritzke, unpubl. data). However, the occurrence of more elm in diets from unburned treatments is interesting since stem density of elm on unburned treatments was about 7% lower than on burned treatments (J. F. Stritzke, unpubl. data). Thus suggesting that eastern woodrats on burned treatments are selecting for other dietary items, such as pokeweed. The occurrence of eastern redcedar in diets failed to show differences among experimental brush treatments. This is probably related to the lack of control that herbicides had on eastern redcedar and their uniform distribution on the CTER (Stritzke et al. 1987).

Differences in diet quality may have special implications regarding populations of eastern woodrats and other small mammals. Increased quality of the diet can increase reproductive potential in females (Merson 1979, Bomford and Redhead 1987). Keith et al. (1959) monitored populations of pocket gophers (Thomomys talpoides) following 2,4-D application and found the forb-dominated diet to shift to near equal parts grass and forbs once forb production declined. A decline in the population level of pocket gophers accompanied the dietary shift.

Johnson (1964) noted that small mammal species may shift their diet as a result of habitat alteration with herbicides. Eastern woodrats on the CTER have obviously experienced dietary shifts and in most cases, dietary items appear to be utilized relative to their abundance. Our results confirm other observations (Rainey 1956, Wiley 1980) and suggest that eastern woodrats are opportunistic relative to their diet preferences.

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Table 1. Relative percentage of plant species found in diets of eastern woodrats in summer and winter 1986.

Species	Summer	Winter
Elm	17.46	0.33
Eastern redcedar	1.62	77.34
Tick clover	6.30	--
Pokeweed	35.73	0.09
Western ragweed	0.28	5.72
Coralberry	3.88	--
Bedstraw (*Galium* spp.)	1.13	--
Evening primrose (*Oenothera laciniata*)	0.08	--
Hackberry (*Celtis* spp.)	4.41	0.01
Wild lettuce (*lactuca canadensis*)	1.18	--
Morning glory (*Ipomoea purpurea*)	0.69	--
Plum (*Prunus* spp.)	3.08	--
Fungi	4.26	5.60
Ox-eye daisy (*Chrysanthemum leucanthemum*)	1.94	--
Grape (*Vitis* spp.)	9.21	3.09
Goldenrod (*Solidago* spp.)	0.13	--
Sunflower (*Helianthus* spp.)	0.21	--
Violet (*Viola* spp.)	0.11	--
Wing sumac (*Rhus copallina*)	0.01	--
Geum (*Geum vernum*)	--	0.16
Greenbriar (*Smilax* spp.)	--	2.12
Pussy's toes (*Antennaria* spp.)	--	0.14
Unk. forb/browse	4.66	5.13
Unk. grass	0.16	0.14

Table 2. Plant species richness and diversity of diets of eastern woodrats from experimental brush treatments in summer and winter 1986.

	Season and treatment									
	Summer					Winter				
	Teb	Teb/f	Tric	Tric/f	Cont	Teb	Teb/f	Tric	Tric/f	Cont
Species richness	8	7	12	12	9	6	5	5	5	4
Species diversity	1.78	1.00	1.82	2.71	2.01	0.72	0.92	1.30	1.43	0.18

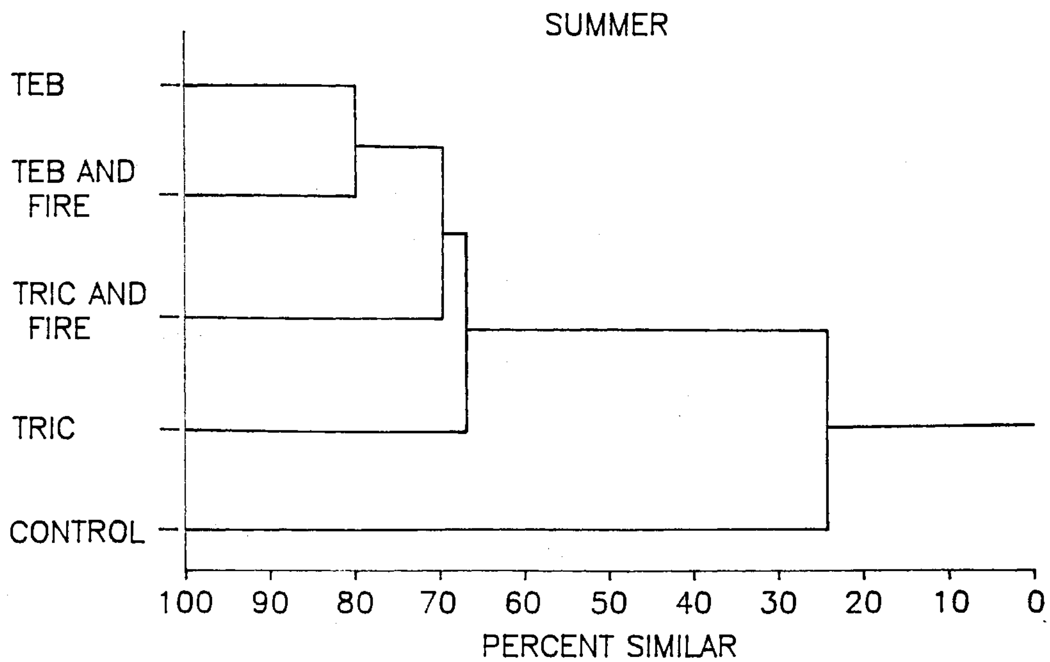
Table 3. Relative percentage of major and minor plant species in total diets of eastern woodrats from experimental brush treatments in summer and winter 1986.

	Season and Treatment									
	Summer					Winter				
	Teb	Teb/f	Tric	Tric/f	Cont	Teb	Teb/f	Tric	Tric/f	Cont
<u>Major</u>[a]										
Elm	9.6	1.0	51.7	5.1	2.8	0	0	0	0	1.7
Redcedar	0	0	0	3.9	1.3	76.5	78.6	69.4	67.1	93.8
Pokeweed	55.0	81.1	23.1	38.6	0.2	0	0.5	0	0	0
Tick clover	3.8	6.8	3.7	10.8	0.6	0	0	0	0	0
Western ragweed	4.7	0.2	5.8	3.1	1.7	0.1	0	0.7	0	0
Potentilla	0	0.3	0	0.7	0	4.7	15.5	2.1	5.6	0.5
<u>Minor</u>[b]										
Fungi	0	0	0	0	31.0	4.7	0	11.1	13.7	0
Grape	0	0	0.4	13.9	28.6	0.5	2.8	0	12.0	0

[a] Plant species represented in all experimental treatments in either season.

[b] Plant species comprising $\geq 10\%$ of the diet but not occurring in diets from all experimental treatments.

Figure 1. Dendrogram depicting similarity of plant species composition in diets of eastern woodrats from experimental brush treatments in summer and winter 1986.


SUMMER
TEB
TEB AND FIRE
TRIC AND FIRE
TRIC
CONTROL
100 90 80 70 60 50 40 30 20 10 0
PERCENT SIMILAR

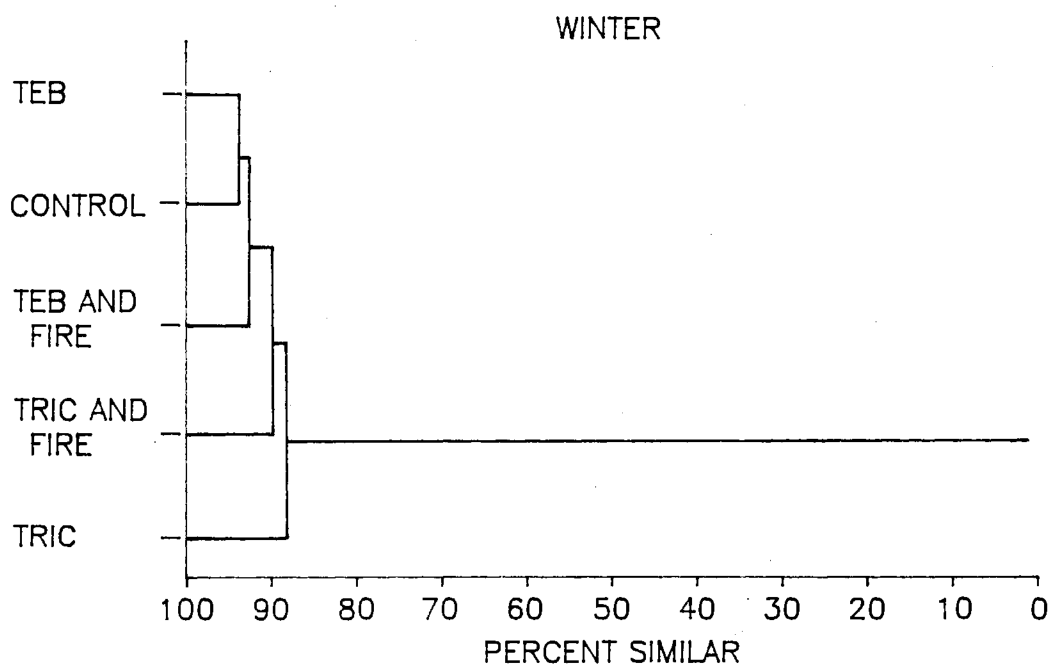
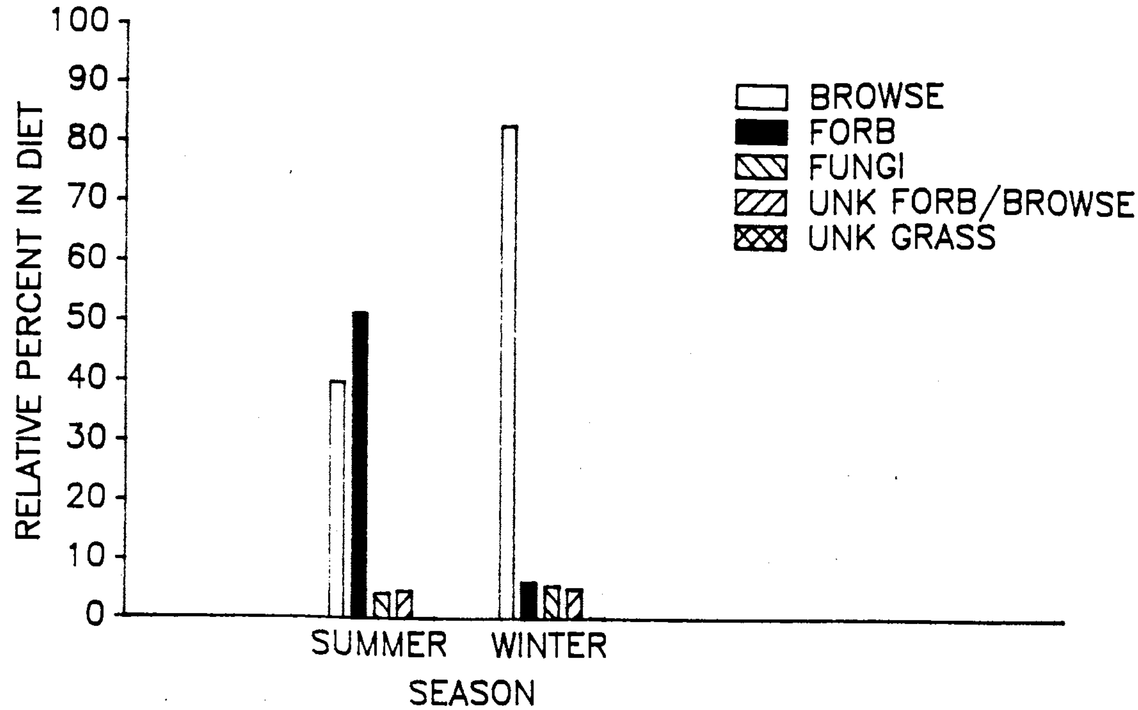

WINTER
TEB
CONTROL
TEB AND FIRE
TRIC AND FIRE
TRIC
100 90 80 70 60 50 40 30 20 10 0
PERCENT SIMILAR

Figure 2. Differences in relative percent coverage of browse, forbs, fungi, and unknown forb/browse and grass in diets of eastern woodrats among seasons and experimental brush treatments in 1986.


100
90
80
70
60
50
40
30
20
10
0
RELATIVE PERCENT IN DIET
BROWSE
FORB
FUNGI
UNK FORB/BROWSE
UNK GRASS
SUMMER
WINTER
SEASON

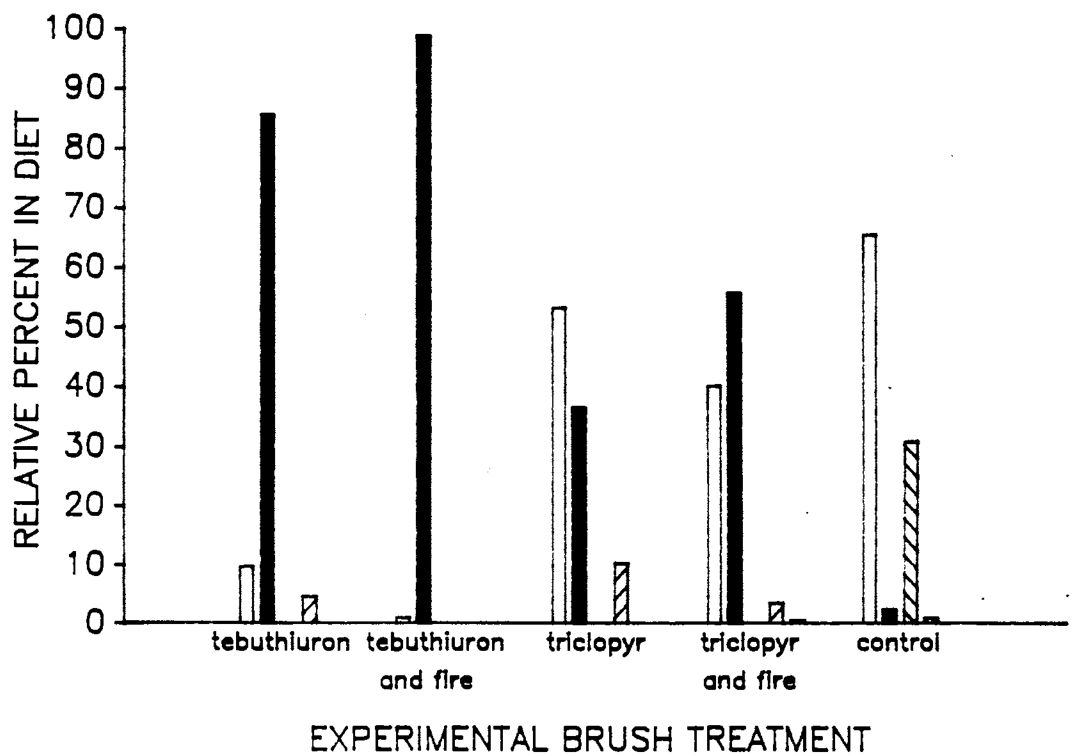
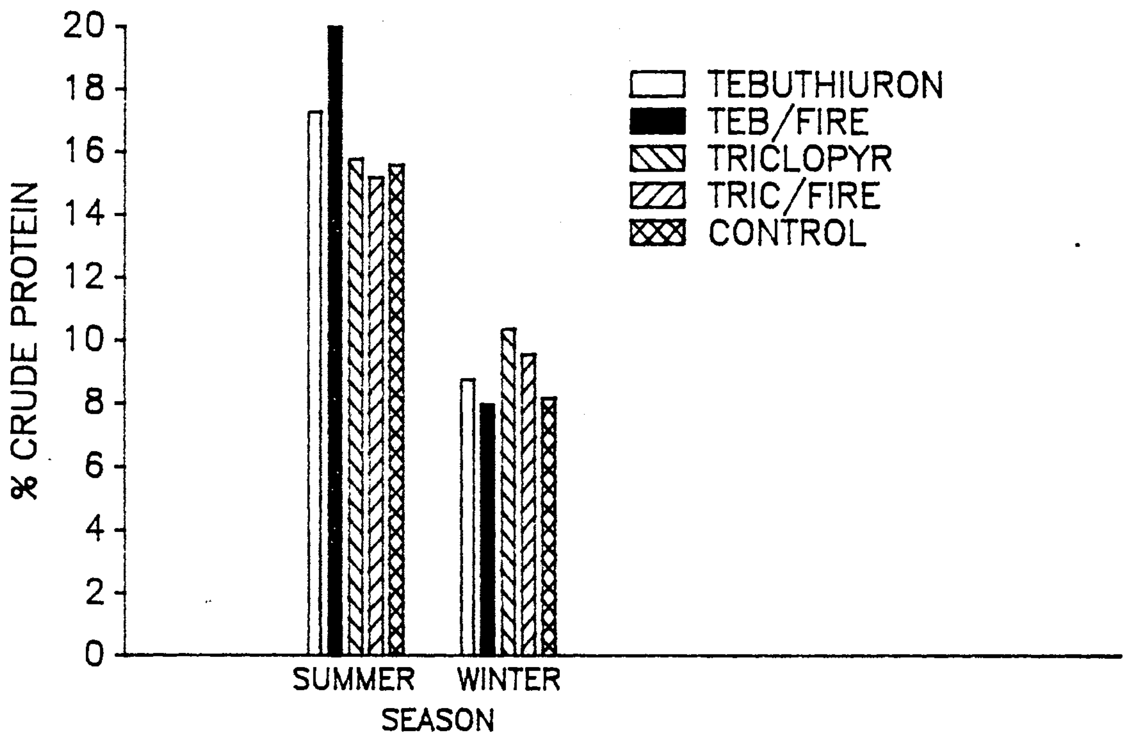

100
90
80
70
60
50
40
30
20
10
0
RELATIVE PERCENT IN DIET
tebuthiuron
tebuthiuron and fire
triclopyr
triclopyr and fire
control
EXPERIMENTAL BRUSH TREATMENT

Figure 3. Differences in average percent crude protein in diets of eastern woodrats from experimental brush treatments in summer and winter 1986.



20
18
16
14
12
10
8
6
4
2
0
% CRUDE PROTEIN
TEBUTHIURON
TEB/FIRE
TRICLOPYR
TRIC/FIRE
CONTROL
SUMMER
WINTER
SEASON

APPENDIXES

APPENDIX A

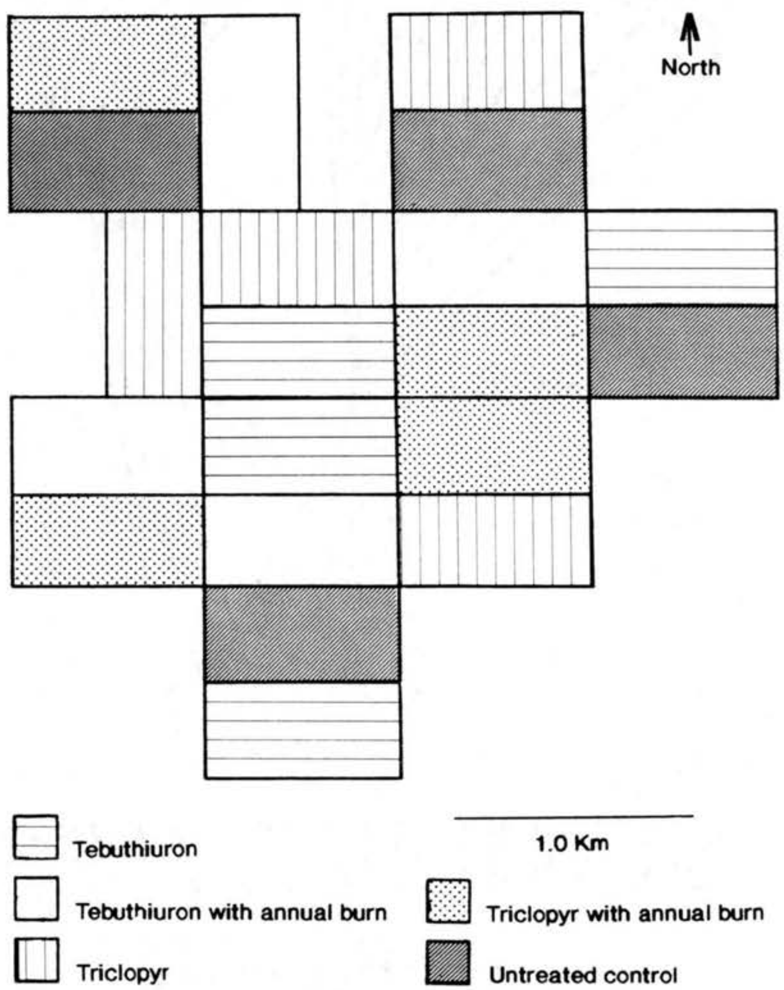
SUMMARY OF EXPERIMENTAL TREATMENT EFFECTS ON RELATIVE POPULATION DENSITY OF SMALL MAMMAL POPULATIONS

Experimental brush treatment	General habitat description	General response of small mammal populations
Tebuthiuron	Nearly 100% of the dominant overstory killed. Increased grass and forb standing crop.	White-footed mice and cotton rats responded to this treatment with peak density in winter 1986. Eastern woodrats failed to respond to this treatment.
Tebuthiuron and burning	Nearly 100% of the dominant overstory killed. Increased grass and forb standing crop. Burning created a mosaic of burned and unburned patches.	Cotton rats reached their highest density with peak in winter 1986. White-footed mice responded with peak in spring 1987. Eastern woodrats failed to respond.
Triclopyr	Nearly 100% of the dominant overstory killed. Increased grass and forb standing crop. Structurally diverse vegetation composition.	White-footed mice and eastern woodrats responded with peaks in spring 1986 and summer of each year, respectively. Cotton rats responded with peak in winter 1986.
Triclopyr and burning	Nearly 100% of the dominant overstory killed. Increased grass and forb standing crop.	White-footed mice responded with peak in spring 1986. Eastern woodrats responded as on triclopyr

Experimental brush treatment	General habitat description	General response of small mammal populations
	Burning produced a mosaic of burned and unburned patches. Structurally diverse vegetation composition.	treatments. Cotton rats responded with peak in winter 1986.
Untreated control	Upland sites dominated by post and black-jack oak with interspersed grassland/cedar sananna. Dominant understory vegetation included coral-berry, elm, and western ragweed. Structural complexity comparable to triclopyr treatments.	Overall, relative population density of all 3 small mammal species lower on this treatment compared to other experimental treatments.

APPENDIX B

MAP OF THE CROSS TIMBERS EXPERIMENTAL RANGE


North
Tebuthiuron
Tebuthiuron with annual burn
Triclopyr
Triclopyr with annual burn
Untreated control
1.0 Km

VITA

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Master of Science

Thesis: EFFECTS OF HABITAT MODIFICATION WITH HERBICIDE AND PRESCRIBED BURNING ON SMALL MAMMAL POPULATIONS INHABITING CROSS TIMBERS RANGELAND IN OKLAHOMA

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