EFFECT OF LAND-USE MANIPULATIONS ON HABITAT ASSOCIATIONS AND DEMOGRAPHY OF MESOCARNIVORES IN THE CROSS TIMBERS ECOREGION OF OKLAHOMA

By

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CHAPTER I

EFFECTS OF VEGETATION MANAGEMENT ON MAMMALIAN MESOCARNIVORES IN THE CROSS TIMBERS ECOREGION OF OKLAHOMA

ABSTRACT

Changes have occurred to the landscape with increases in the human population and human encroachment on open space. Anthropogenic conversion of native habitats has resulted in alteration or loss of habitats for a variety of species. I livetrapped 626 individuals of 3 mesocarnivores (raccoon, *Procyon lotor;* opossum, *Didelphis virginiana*; and striped skunk, *Mephitis mephitis*) to examine effects of habitat manipulation on mesocarnivore community structure. Trapping occurred in spring, summer, and fall, 1998-1999. My study area was the Cross Timbers Experimental Range, 680-ha treated in 32.4-ha patches with combinations of herbicides and burning to derive 5 habitat types: oak (*Quercus* spp.) forest, mixed-brush, grassland, eastern redcedar (*Juniperus virginiana* L.) forest, and forest edge. Raccoons were distributed evenly across habitats, whereas opossums were more prevalent in scrub-shrub and oak habitats. Separate analyses for opossum and raccoon capture data revealed winter burning on herbicide treatments between trapping years was associated with a study-area-wide decrease in opossum numbers in the following spring and summer. Raccoons shifted among habitat patches by season but did not appear affected adversely by burning. Herbicide and burning treatments influenced mesocarnivore community composition in the Cross Timbers ecoregion, and these effects varied temporally.

INTRODUCTION

Changes have occurred to the landscape with increases in human population size and encroachment on open spaces. Conversion of native habitats by anthropogenic disturbances has resulted in alteration or loss of habitats for a variety of species. The guild of medium-sized (1-10 kg) mammalian carnivores, or mesocarnivores, responds directly with increasing numbers to anthropogenic disturbances and increased habitat heterogeneity (Oehler and Litvaitis 1996). Mesocarnivores also respond with larger numbers indirectly from loss of large carnivores (e.g., mountain lions, *Felis concolor*; gray wolf, *Canis lupus*) via mesopredator release (Fitch and Sandidge 1953, Palomares et al. 1995). Because mesocarnivores have broad omnivorous diets, they perform a pivotal role in population management of species at lower trophic levels and can influence vegetation recruitment in a top-down manner (Hunter and Price 1992, Asquith et al. 1997).

Mesocarnivores have been the subject of recent ecological and conservation interest because of relationships among these species, habitat fragmentation, and predation rates on avian species (Donovan et al. 1995), especially in agricultural landscapes (Dijak and Thompson 2000). Increased landscape diversity in New Hampshire was associated with increased activity of generalist carnivores (raccoon [*Procyon lotor*], red fox [*Vulpes vulpes*], and coyote [*Canis latrans*]; Oehler and Litvaitis 1996). These mesocarnivore species benefited not directly from increased habitat diversity but from an increase in anthropogenically altered habitats (e.g., agriculture, grass-brushlands, and developed areas) from 7 to 27% of the areas studied (Oehler and Litvaitis 1996). In Missouri, raccoon activity was higher in forest edges adjacent to agricultural areas or streams, although opossums (*Didelphis virginiana*) showed a relationship with stream density (Dijak and Thompson 2000). High mesocarnivore activity coupled with no edge effect was attributed to the lack of a true forest interior (Heske 1995) and density saturation in all habitats (Heske et al. 1999) in Illinois. Predation rates of artificial nests by mammalian predators (e.g., raccoons, opossums) were higher in highly fragmented landscapes than unfragmented landscapes (Donovan et al. 1997). Mesocarnivore ecology in contiguous managed forests (Kissell and Kennedy 1992, Chamberlain et al. 1999) has been studied less than in agriculturally fragmented landscapes.

The Cross Timbers ecoregion spans large parts of central Oklahoma and Texas and is characterized by oak (*Quercus* spp.) forest invaded by eastern red cedar (*Juniperus virginana* L.) and interspersed with prairie (Ewing et al. 1984). The major land use in this region is livestock production. Several studies have examined methods (e.g., chemical, burning, mechanical) to manage vegetation with the long-range goal of increasing productivity for livestock in this region (Allen et al. 1976, Engle et al. 1991, Stritzke et al. 1991) and other brush habitats (Scifres and Mutz 1978, Scifres and Koerth 1986). Other studies have examined effects of these management regimes on small mammals in the Cross Timbers (McMurry et al. 1993, 1994, 1996), cottontails (*Sylvilagus floridanus*; Lochmiller et al. 1991), song birds (Schultz et al. 1992*a*, 1992*b*), and herpetological communities (Jones et al. 2000). Noticeably missing from studies exploring the impacts of management practices on wildlife species have been examinations of land-use effects on the structure and abundance of mesocarnivores.

Mesocarnivores extant in the Cross Timbers ecoregion include raccoon, opossum, striped skunk (*Mephitis mephitis*), gray (*Urocyon cinereoargenteus*) and red foxes, coyote, and bobcat (*Lynx rufus*). Diets of the former 3 species (raccoon, opossum, striped skunk) can show considerable overlap, with varying amounts of fruits, mast, invertebrate, and vertebrate matter (Wood 1954). Raccoons thrive in anthropogenically disturbed areas and have increased their distribution with human influence. Preferred habitats of raccoons include areas associated with water, such as bottomland hardwoods and swamps (Sanderson 1987, Kaufmann 1982). Some drier areas, such as upland hardwood forests, are used, but pine or pine-hardwood stands generally are avoided (Shirer and Fitch 1970, Kaufmann 1982, Sanderson 1987, Kissell and Kennedy 1992). Opossums are similar to raccoons in their ability to thrive in anthropogenically disturbed areas. They prefer wet shrubby thickets, forest edges, and areas close to water (Seidensticker et al. 1987, Kissell and Kennedy 1992). Opossums are prevalent in deciduous forests with stream associations, marshlands, agricultural lands, and grasslands (Gardner 1982, McKeever 1959). Striped skunks occur in a variety of habitats including agricultural fields, forested areas, edges associated with fields and forests, and wooded ravines with water (McKeever 1959, Godin 1982, Rosatte 1987).

I investigated effects of vegetation management (combinations of prescribed burning and herbicides) on the distribution and abundance of mesocarnivores in the Cross Timbers ecoregion of Oklahoma. My specific objectives were to compare capture rates and frequencies of different mesocarnivores among management treatments. Based on habitat associations in the literature, I predicted that raccoons would be found primarily in treatments with a high component of deciduous hardwood and scrub-shrub type forests; opossums would be distributed equally among treatment types; and striped skunks would be found in grasslands, cedar forests, and along edges.

STUDY AREA

The Cross Timbers Experimental Range (CTER), owned by Oklahoma State University, has been used since 1983 to study interactions of vegetation management (Engle et al. 1991, Stritkze et al 1991), livestock production and wildlife in the Cross Timbers. CTER is located 11 km southwest of Stillwater, Payne County, OK (36°02'40" to 36°04'20"N, 97°09'30" to 97°11'39"W). The overstory is primarily post oak (*Quercus stellata* Wang.), blackjack oak (*Q. marilandica* Muench.), and American elm (*Ulmus americana* L.) interspersed with eastern redcedar. Little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], indiangrass [*Sorgahastum nutans* (L.) Nash.], swithgrass (*Panicum virgatum* L.), grama grasses (*Bouteloua* spp.), purpletop [*Tridens flavus* (L.) Hitchc.], ragweed (*Ambrosia* spp.), and buckbrush (*Symphoricarpos orbiculatus* Moench.) are prevalent in the understory (Ewing et al. 1984).

The land-use history of CTER started as homestead and private cultivation of crops such as cotton (Ewing et al. 1984). In 1983, a regime of herbicide, fire, and combinations of each was prescribed to examine ecosystem response. The area now encompasses 712 ha comprising 22, 32.4-ha pastures (Fig. 1). Pastures have undergone different treatment regimes, producing a landscape mosaic of habitat types. The CTER comprise 5 experimental treatments randomly assigned within 4 replicate groups blocked by soil type and original total woody canopy cover. Treatments were tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N`-dimethylurea, Dow Elanco, Indianapolis, Indiana, USA) applied aerially at 2.2 kg/ ha in March 1983; tebuthiuron with prescribed burning; triclopyr ([(3,5,6-trichlor-2-pyridinyl)oxy]acetic acid, Dow Elanco) applied aerially at 2.2 kg/ha in June 1983; and triclopyr with prescribed burning; and control (no herbicide or burning; Table 1). The triclopyr alone treatment was supplemented with prescribed fire starting in 1996 on a 3-year cycle.

Tebuthiuron is a soil-applied herbicide absorbed through root systems. Application at CTER resulted in die-off of most woody species, thereby allowing eastern redcedar to become established. Triclopyr is a foliar-applied herbicide absorbed through the leaf surface that primarily kills broadleaf species including deciduous woody plants. When aerially applied, it allows release of understory woody species if the overstory is sufficiently dense to intercept the herbicide. When either herbicide treatment is combined with a spring headfire regime, remaining woody species are reduced (Engle et al. 1991, Stritzke et al. 1991). Four derived habitat types resulted from treatments applied (D.M. Engle, *personal communication*): eastern redcedar forest, derived grassland, brush-grassland community, and mature oak forest (Table 1, 2). The 4 habitat types resulting from the treatments were validated by classifying habitat types on an 1998 aerial black-and-white photograph (scale 1:4,875) with the aid of extensive ground reconnaissance. I classified the habitats using % vegetative composition as the criteria for classification (Table 3).

METHODS

Experimental Design and Sampling

Four of the 5 experimental treatments were sampled for mesocarnivores: tebuthiuron only, tebuthiuron with fire, triclopyr with recent fire, and control pasture. Triclopyr with fire produced a derived grassland habitat similar to the tebuthiuron with burning treatment (D. M. Engle, *personal communication*) and was not sampled due to logistical constraints. Edges between treated pastures also were sampled as a separate treatment.

There were 4 replicates of each treatment except for the tebuthiuron treatment, which lost a replicate to a wildfire that burned most of the pasture in 1996.

Trapping was conducted seasonally in 1998 and 1999, with 4 consecutive 10-day trapping periods (1 period/replicate/season). Seasons were defined as spring (Apr-May), summer (Jul-Aug), and fall (Sep-Nov). Burning was conducted between trapping sessions in fall 1998 and spring 1999. In pasture interiors, trapping grids were set up in a variation of a 3 x 5 grid for a total of 8 traps (Fig. 2). Traps were located 100 m from edges of the pasture to diminish edge effects. Traps were located 300 m apart along 3 parallel transects spaced at 100-m intervals, and there was 2 interior traps that were 180 m diagonally from the corners (Fig. 2). Edges were trapped along the long axis of the pastures starting 200 m from a pasture corner with traps placed every 200 m. Eight edge traps were open in each 10-day trapping period to equalize representation among pastures. Due to a limited number of traps, edge areas were not trapped during summer 1998. Traps were checked daily.

Animals were sampled using Tomahawk (Tomahawk Trap Company, Tomahawk, Wisconsin, USA) wire-mesh traps (25 x 30 x 81 cm) baited with sardines. Animals were identified by species, anesthetized with Telazol (tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Supply, Fort Dodge, Iowa, USA) at 8 mg/kg estimated body mass, ear-tagged with #4 Monel tags (National Band and Tag, Newport, Kentucky, USA), sexed, aged (adult, juvenile), and weighed (kg) with a spring scale (Chatillon Scale Company, New York, New York, USA). Total length and length of tail, hindfoot, ear, and canine tooth were recorded on the left side of the body to the nearest 1.0 mm with a flexible tape. Animal location was recorded as a replicate –treatment code combination and trap-site number. If an animal had been captured before in a 10-day trapping session, it was released following recording of species, ear-tag number, and location. If an individual was captured before, but not during the current trapping season, it was handled as a new capture.

Statistical Analysis

Unique captures were defined as initial captures of an individual during a particular trapping season, although those individuals may have been captured in previous trapping seasons. Total captures included unique captures and recaptures made within a season. Relative abundance (captures/100 trap nights) was analyzed with a 3-way analysis of variance (ANOVA), with season, treatment, and year as main effects and all interactions of the effects (PROC MIXED, SAS Institute Inc.1990) for raccoons, opossums, and striped skunks separately. Differences among seasons, years, and treatments were analyzed using least square means because of no tebuthiuron-alone treatment in replicate 1. Relative abundance within a replicate group served as the experimental unit. I assumed that 1) attractiveness of baited traps was independent of pasture treatment; and 2) the probability of being trapped in a particular pasture was proportional to use of that treatment for foraging and movements. Data from other mesocarnivores (e.g., gray fox) and non-target species (e.g., box turtles [*Terrapene* spp.], armadillo [*Dasypus novemcinctus*]) were too sparse for analysis but are reported for descriptive purposes. Capture frequencies also were pooled across replicate pastures and analyzed by log-linear analysis (PROC CATMOD, SAS Institute Inc. 1990) to explore effects of species (raccoon, opossum), season, treatment, and year, and all interactions.

RESULTS

Overview

Sampling effort equaled 4,150 trap nights in 1998 and 4,560 trap nights during 1999. Opossums and raccoons were the most commonly captured mesocarnivore, with striped skunks and gray fox captured less frequently (Table 4). Other captures included 18 eastern woodrats (*Neotoma floridanus*), 25 armadillos, 2 eastern cottontails (*Sylvilagus floridanus*), and 31 box turtles (Fig. 3). Distribution of the 3 most abundant species captured across treatments varied for both unique ($\chi^2_8 = 31.8$, $P < 0.001$) and total captures ($\chi^2_8 = 29.5$, $P = 0.003$). Opossums were captured most commonly in control pastures, raccoons were equally distributed among treatments, and skunks were associated with edges and derived grasslands of the tebuthiuron and fire treatment (Fig. 4).

Catch Per Unit Effort

Relative abundance of opossums based on unique and total captures varied among treatments (unique: $F_{4, 78} = 11.87$, $P < 0.001$; total: $F_{4, 78} = 8.42$, $P < 0.001$), with capture rates in control pastures (unique: 4.4 $\pm$ 0.6 SE; total: 9.0 $\pm$ 1.3) greater than all other treatments. Treatments with triclopyr with recent fire (unique: 1.7 $\pm$ 0.3; total: 6.3 $\pm$ 1.0) and edge (unique: 2.1 $\pm$ 0.5; total: 4.8 $\pm$ 0.9) were intermediate, and tebuthiuron with (unique: 3.2 $\pm$ 0.3; total: 3.2 $\pm$ 0.7) and without (unique: 1.3 $\pm$ 0.4; total: 4.1 $\pm$0.7) fire were least. Only control pastures differed ($P < 0.05$) from the other pastures. There was a trend toward an interaction between treatment and years ($F_{4,78} = 1.98$, $P = 0.11$), with controls greater than the 3 herbicide (with or without burning) treatments in 1998, but only greater than tebuthiuron with and without fire in 1999.

Relative abundance of unique and total opossum captures varied with the season by year interaction (unique: $F_{2,78} = 8.15$, $P = 0.001$; total: $F_{4,78} = 5.96$, $P = 0.004$; Table 5), with capture rates being equal among seasons in 1998 (unique: $P = 0.817$; total: P = 0.549) but varying by season in 1999 (unique: $F_{2,39} = 16.33$, $P < 0.001$; total: $F_{2,39} = 29.99$, $P < 0.0001$). In 1999, relative abundance was greater in fall than spring and summer.

Relative abundance of unique raccoon captures tended toward an interaction of season with treatment ($F_{8,78} = 1.73$, $P = 0.104$; Fig. 5), with abundance high in controls and tebuthiuron in the spring, tebuthiuron with fire and triclopyr with fire in summer and triclopyr with fire and controls in fall (Fig. 5). Total relative abundance of raccoons also tended to vary by treatment ($F_{4,78} = 2.45$, $P = 0.053$), with controls having higher relative abundance than tebuthiuron with fire, triclopyr with recent fire, and edge pastures.

Relative abundance of total raccoon captures varied by a season-by-year interaction ($F_{2,78} = 6.15$, $P = 0.003$; Table 5), whereas unique raccoon captures tended toward a similar interaction ($F_{2,78} = 2.33$, $P = 0.104$). Capture rates increased from spring to fall in 1998 but decreased from spring to fall in 1999. Values in spring 1999 were greater ($P < 0.05$) than in spring 1998 and fall 1999.

Relative abundance of striped skunks for unique captures had a season-by-year interaction ($F_{2,78} = 4.71$, $P = 0.012$; Table 5), with greater values in fall 1999 than in any other season. Total relative abundance of striped skunks varied by season ($F_{2,78} = 7.66$, $P < 0.001$), with spring and summer capture rates lower than in fall.

Variation in Capture Frequency

Analysis of capture frequencies for the 2 most abundant species (raccoons, opossums) indicated a trend toward a species by treatment interaction ($\chi^2_4 = 8.52$, $P = 0.074$; Fig. 6). Opossums were found more frequently in control pastures and least frequently in the 2 tebuthiuron treatments, whereas raccoons were found in all treatments with relatively equal frequency. There also was a species-by-season-by-year interaction for unique ($\chi^2_2 = 10.99$, $P = 0.0041$) and total captures ($\chi^2_2 = 29.51$, $P < 0.001$; Table 6). In 1998, captures of both species increased seasonally into fall. In 1999, the seasonal pattern of opossum captures was similar to 1998, although the increase in fall was accentuated. Raccoon captures decreased from spring to fall in 1999. The season-by-treatment-by-year interaction ($\chi^2_8 = 15.96$, $P = 0.04$) also was significant. All other interactions were not significant ($P > 0.248$).

I explored the 3-way interaction (treatment by season by year) with separate analyses by species. Frequencies of unique opossum captures tended toward a season-by-year interaction ($\chi^2_2 = 5.56$, $P = 0.06$; Fig. 7), whereas frequencies of total captures exhibited a strong season by year interaction ($\chi^2_2 = 20.17$, $P < 0.001$; Fig. 8). In both years, opossum captures peaked in fall, with a stronger fall pulse in 1999. Frequency of total opossum captures also interacted with season, treatment, and year ($\chi^2_6 = 12.52$, $P = 0.051$; Fig. 9). In spring and summer 1998 (pre-burning), captures in control pastures numbered more than all other treatments, whereas in 1999 (post-burning), capture frequencies in spring and summer were lower overall with no distinct preferences shown for any treatment. Distribution of captures across treatments was similar in fall for both years. All other interactions were not significant ($P > 0.159$).

Frequencies of unique and total captures of raccoons showed a season-by-year interaction (unique: $\chi^2_2 = 6.65$, $P = 0.036$; total: $\chi^2_2 = 15.25$, $P < 0.001$, Fig. 10) with increasing frequency of captures from spring to fall in 1998 and the reverse in 1999. All other interactions were not significant ($P > 0.113$).

DISCUSSION

The structure of the mesocarnivore community varied with type of treatment applied in this managed Cross-Timbers ecosystem. Species habitat preferences contributed to links between mesocarnivore community composition and habitat treatment. For example, relative abundances of striped skunks were consistent with previous work that showed that striped skunks preferred open or edge areas (Rosatte 1987, Bixler and Gittleman 2000). These habitats were more abundant in the herbicide with burning treatments (Table 2), which produced derived grasslands interspersed with shrubs and trees. Skunks may prefer these habitats for foraging, either for insects or nesting birds (Godin 1982, Rosatte 1987). Increased abundance of grasshoppers was found in spring-burned areas (Dunwiddie 1991). Skunks may have preferred fenceline edges because of an increased abundance of nesting birds (Donovan et al. 1997, Paton 1994). Increased fall relative abundance may be a consequence of increased movement of young skunks within the area (Wade-Smith and Verts 1982).

Treatment differences in the relative abundance of raccoons and opossums were comparable with previous work on habitat associations of these 2 species in sympatry. McKeever (1959) reported that catch per effort indices of raccoons were similar across several vegetative types (tall weeds-broomsedge, cultivated areas, pine-hardwoods, upland hardwoods, and bottomland hardwoods), which was consistent with the breadth of raccoon captures across treatments on my study area. Opossums were captured at higher rates in pine-hardwoods, bottomland hardwoods, and tall weeds-broomsedge types (McKeever 1959), which corresponded roughly to the vegetative associations on control and triclopyr-with-recent-fire treatments on CTER that opossums preferred. Conversely, work on habitat associations of raccoons and opossums in Tennessee (Kissell and Kennedy 1992) indicated that in heterogeneous habitat (i.e., a mixture of pine forest, hardwood forest, and pastures), opossums used nearly the entire area but raccoons were limited to hardwood habitats. Those authors concluded that raccoons and opossums occurred independently of each other.

However, I speculate that the composition of the study area of Kissell and Kennedy (1992) differed from CTER. Although Kissell and Kennedy (1992) worked in heterogeneous habitat in Tennessee, the area was broadly classified as heterogeneous and may be distinctly different from the heterogeneous nature of CTER. CTER may have a higher degree of fragmentation and therefore smaller patch size than the study area of Kissell and Kennedy (1992). Overall patch size on CTER was 1.5 ha ($n = 474$), with grassland patches averaging 4.8 ha ($n = 87$), oak patches averaging 2.8 ha ($n = 45$), and cedar patches averaging 1.0 ha ($n = 63$). That contrast may account for the difference in habitat associations reported between my study and that of Kissell and Kennedy (1992).

The interaction of treatment scale and ranging behavior of raccoons and opossums also may have contributed to the treatment pattern in species composition. For example, raccoon home ranges are 40-100 ha (Kaufmann 1982), whereas opossum home ranges are 4.7-82.2 ha (Gardner 1982), with 20.2 ha being the average size for opossums (Fitch and Sandidge 1953). Raccoons also make long-range movements up to 5.6 km to temporary food sources (Fritzell 1978), easily spanning the entire CTER. In contrast, long-range movements of opossums are usually <1 km (Gardner 1982, Seindensticker et al. 1987). Given these differences in home-range size and scale of movement, raccoons could readily cover several pastures in daily movements, whereas opossums likely would be limited to 1-2 pastures of strong preference. Raccoons would thus more likely be captured with an even distribution among treatments than opossums.

The variation in opossum abundance across seasons and years could be a result of burning and the low apparent survival rate of opossums (see Chapter 2). Total capture frequency in the spring 1999 roughly equaled the number of captures in the unburned areas in fall 1998. If burning influenced mortality of opossums or caused opossum emigration, remaining opossums in the unburned pastures may have dispersed into those pastures burned during spring. This is similar to the theory of ideal-free distribution (Fretwell 1972), where an animal can obtain the same amount of resources in a lower-quality habitat because there is less competition for those resources than in a higher quality habitat. Burning may thus explain the overall decrease in opossum abundance during spring and summer 1999. Subsequently, vegetative recovery of the landscape from burning and production of young (Gillette 1980) may have led to opossum abundance reaching pre-burning levels by fall.

The season-by-treatment interaction observed for relative abundance of raccoons may be explained by seasonal changes in foraging behavior. For example, raccoons were more likely to be captured in control and triclopyr-with-recent-fire pastures in fall. Control pastures and triclopyr-with-recent-fire pastures have a high abundance of hard and soft-mast-producing species (Stritzke et al. 1991), which compose a large portion of raccoon diets (Llewellyn and Uhler 1952, Wood 1954). Control areas also offer denning and daytime resting sites. Edge areas and control pastures also could be used because nesting birds and acorns are still available as source of food in spring. Summer preference of treated pastures could be due to increased availability of soft mast, a component of raccoons summer diet (27% by volume; Baker et al. 1945).

Raccoon abundance remained at similar levels immediately pre- and post-burning. Perhaps fire had a minimal effect on raccoons as previously reported by Sunquist (1967), or due to raccoons being highly mobile habitat generalists, thereby allowing raccoons to deal with the short-term change in the landscape by shifting to suitable areas. In fall 1999, the low abundance could have been due to dispersal of young raccoons from their mothers (Lotze and Anderson 1979) and emigration because of the high density in summer 1999 (Chapter 2).

The role of spatial scale in the study of mesocarnivores has received attention in recent years (Pedlar et al. 1997, Dijak et al. 2000). Increased habitat fragmentation has resulted in more edge area (Heske et al. 1999). Many studies have reported that nesting birds have decreased success in and around edge areas because of increased abundance of predators such as raccoons, opossums, and striped skunks (Angelstam 1986, Small and Hunter 1988, Hartley and Hunter 1998). On CTER, striped skunks were more prevalent in a mosaic of habitats where they used edges and open areas. However, Heske (1995) and Heske et al. (1999) dismissed differences among edge and interior forest areas with regards to nest success.

Studies of responses to treatments on CTER by other vertebrates allow comparisons with mesocarnivore response. Tebuthiuron and triclopyr treatments with fire created more favorable cottontail habitat than controls on CTER (Lochmiller et al. 1991). Densities, however, did not differ among treatments. Densities of cotton rats (*Sigmodon hispidus*) and white-footed mice (*Peromyscus leucopus*) were higher on herbicide with- and without-fire treated sites than on control sites (McMurray et al. 1994, 1996), however, eastern woodrat (*Neotoma floridana*) density was not different between control and burned pastures (McMurray et al. 1993). Raccoon responses were similar to these previous findings on CTER across treatments except that unlike small mammals and cottontails, a slight preference towards controls was displayed. However, habitat use, dietary preferences, and ranging behavior along with ranging behavior of small mammals and cottontails are more limiting than that of raccoons. Opossums, conversely, used tebuthiuron treatments sparingly relative to control and triclopyr treatments. Small mammals and cottontails have more specialized diets than opossums, which could explain differences in treatment preferences. Songbirds did not differ in total density, species richness, and species diversity among treatments (Schultz et al. 1992), however, species composition varied among treatments along habitat preferences from the literature (Ehrlich et al. 1988). Lizards were found more readily in untreated pastures, whereas amphibians were found equally in untreated and herbicide only treated pastures (Jones et al. 2000).

Opossums appeared to be sensitive to treatment-related changes in habitat and may have more stable densities in less-fragmented cross timber forest. Raccoons, on the other hand, seemed unaffected by the heterogeneous habitat composition of CTER at this treatment scale and degree of fragmentation. Generalist predators focused along edges and in patches in large-scale, even landscapes, whereas in more fragmented landscapes no selection was detected (Oehler and Litvaitis 1996). The same selection processes appear to be occurring at CTER, with opossums and raccoons responding differently to the same scale of heterogeneity. However, my results are applicable to the habitats and scale of this study and any extrapolation to other areas should be done with caution. Further study in other areas and at other scales is necessary to augment our understanding of habitat heterogeneity and mesocarnivore ecology.

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Table I.1: Timing of treatment regime at Cross Timbers Experimental Range, Payne County, Oklahoma.

	Treatment regime			
Treatment	Herbicide	Burn	Mechanical	Current Habitat
1	Tebuthiuron 1983	None	None	Cedar forest
2	Tebuthiuron 1983; P+D[b] 1997	1985, 86, 87, 90, 93, 96. 99	None	Derived grassland
3	Triclopyr 1983; 2,4-D 1988; P+D[b] 1994, 1997	1993, 96, 99	Bulldoze and windrow cedar pre-1996; Saw cedar post-1996	Scrub-shrub forest
5	None	None	None	Mature oak forest

[a] D. M. Engle, *personnal communication.*

[b] Picloram + 2,4-D

Table I.2: Average area (ha; $\bar{x} \pm$ SE) and % habitat in each treatment on the Cross Timbers Experimental Range, Payne County, Oklahoma.

Habitat Type	Tebuthiuron only		Tebuthiuron-and-fire		Triclopyr-and-fire		Control	
	Area	%	Area	%	Area	%	Area	%
Grassland	7.2 ± 3.4	20.8 ± 9.8	14.5 ± 1.6	43.5 ± 4.8	9.1 ± 2.1	27.2 ± 6.3	3.4 ± 0.6	10.2 ± 1.8
Oak forest	1.6 ± 1.4	4.6 ± 4.0	1.8 ± 1.1	5.4 ± 3.3	1.7 ± 1.1	5.1 ± 3.3	18.3 ± 2.2	55.0 ± 6.6
Cedar forest	14.4 ± 3.1	41.6 ± 9.0	0.8 ± 0.3	2.4 ± 0.9	3.8 ± 1.3	11.4 ± 3.9	1.7 ± 1.1	5.1 ± 3.3
Grassland-Cedar	3.7 ± 2.9	10.7 ± 8.4	6.0 ± 1.4	18.0 ± 4.2	0.5 ± 0.0	1.5 ± 0.0	1.5 ± 1.4	4.5 ± 4.2
Cedar-Grassland	2.5 ± 0.9	7.2 ± 2.6	4.7 ± 0.8	14.1 ± 2.4	0.4 ± 0.2	1.2 ± 0.6	4.4 ± 1.6	13.2 ± 4.8
Scrub-Shrub forest	1.9 ± 1.6	5.5 ± 4.6	2.0 ± 0.2	6.0 ± 0.6	13.1 ± 1.8	39.2 ± 5.4	0.3 ± 0.2	0.9 ± 0.6
Bottomland	0.8 ± 0.4	2.5 ± 1.2	1.2 ± 0.2	3.6 ± 0.6	0.7 ± 0.1	2.1 ± 0.3	0.9 ± 0.1	2.7 ± 0.3
Cedar-Oak forest	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.9	2.7 ± 2.7	1.0 ± 0.3	3.0 ± 0.9	0.6 ± 0.5	1.8 ± 1.5
Cedar-Non-oak forest	2.5 ± 0.4	7.2 ± 1.2	1.2 ± 0.2	3.6 ± 0.6	2.9 ± 0.3	8.7 ± 0.9	2.2 ± 0.0	6.6 ± 0.0
Pond	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.6 ± 0.0	0.2 ± 0.1	1.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0

Table I.3: Vegetative composition criteria for habitat classification on the Cross Timbers Experimental Range, Payne County, Oklahoma.

Habitat Classification	% Cover Grassland	% Cover Oak Forest	% Cover Redcedar Forest	% Cover Non-Oak Forest
Grassland	>75.0	<10.0	<10.0	<10.0
Grassland-Cedar	>50.0	<10.0	<50.0	<10.0
Cedar-Grassland	<50.0	<10.0	>50.0	<10.0
Cedar forest	<10.0	<10.0	>75.0	<10.0
Oak forest	<10.0	>75.0	<10.0	<10.0
Non-oak forest[1]	<10.0	<10.0	<10.0	>75.0
Cedar-Oak forest	<10.0	25.0-75.0	25.0-75.0	<10.0
Cedar-Non-oak[2]	<10.0	<10.0	25.0-75.0	25.0-75.0

[1] Includes bottomland and scrub-shrub forest.
[2] Includes cedar-scrub forest.

Table I.4: Unique[a] and total captures of mesocarnivores by years at Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

Year	Type of Capture	Opossum	Raccoon	Striped Skunk	Gray Fox
1998	Unique	98	69	13	3
	Total	235	102	19	3
1999	Unique	81	72	24	2
	Total	147	94	29	2

[a] Unique captures refers to initial captures of known individuals made within a trapping season.

Table I.5: Relative abundances (captures / 100 trapnights; $\bar{x}$ ± SE) of opossums (total captures), raccoons (total captures), and striped skunks (unique[a] captures) by season and year on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

Species	Year	Spring	Summer	Fall
Opossum	1998	6.3 ± 1.4	6.5 ± 1.2	7.5 ± 1.0
	1999	2.8 ± 0.7	1.5 ± 0.4	9.1 ± 1.1
Raccoon	1998	2.0 ± 0.5	2.5 ± 0.5	3.5 ± 0.8
	1999	3.7 ± 0.7	2.4 ± 0.5	1.3 ± 0.5
Striped Skunk	1998	0.4 ± 0.1	0.4 ± 0.2	0.9 ± 0.4
	1999	0.7 ± 0.4	0.3 ± 0.2	1.9 ± 0.4

[a]Unique capture is an initial capture of an individual during a particular trapping season.

Table I.6: Frequency of unique and total captures of opossums and raccoons by season and year on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

		Spring		Summer		Fall	
Capture Type	Year	Opossum	Raccoon	Opossum	Raccoon	Opossum	Raccoon
Unique	1998	30	22	32	18	40	28
	1999	17	35	16	23	48	14
Total	1998	81	29	64	27	90	45
	1999	35	45	18	31	91	18

Figure I.1: Pasture layout at the Cross Timbers Experimental Range, Payne County, Oklahoma. Numbers within treatment pastures represent block number (initial digit) and treatment number (terminal digit; 1 = Tebuthiuron; 2 = Tebuthiuron with prescribed fire; 3 = Triclopyr with recent prescribed fire; 4 = Triclopyr with prescribed fire; 5 = Control). HP = Holding pastures, CP = Corral Pasture.

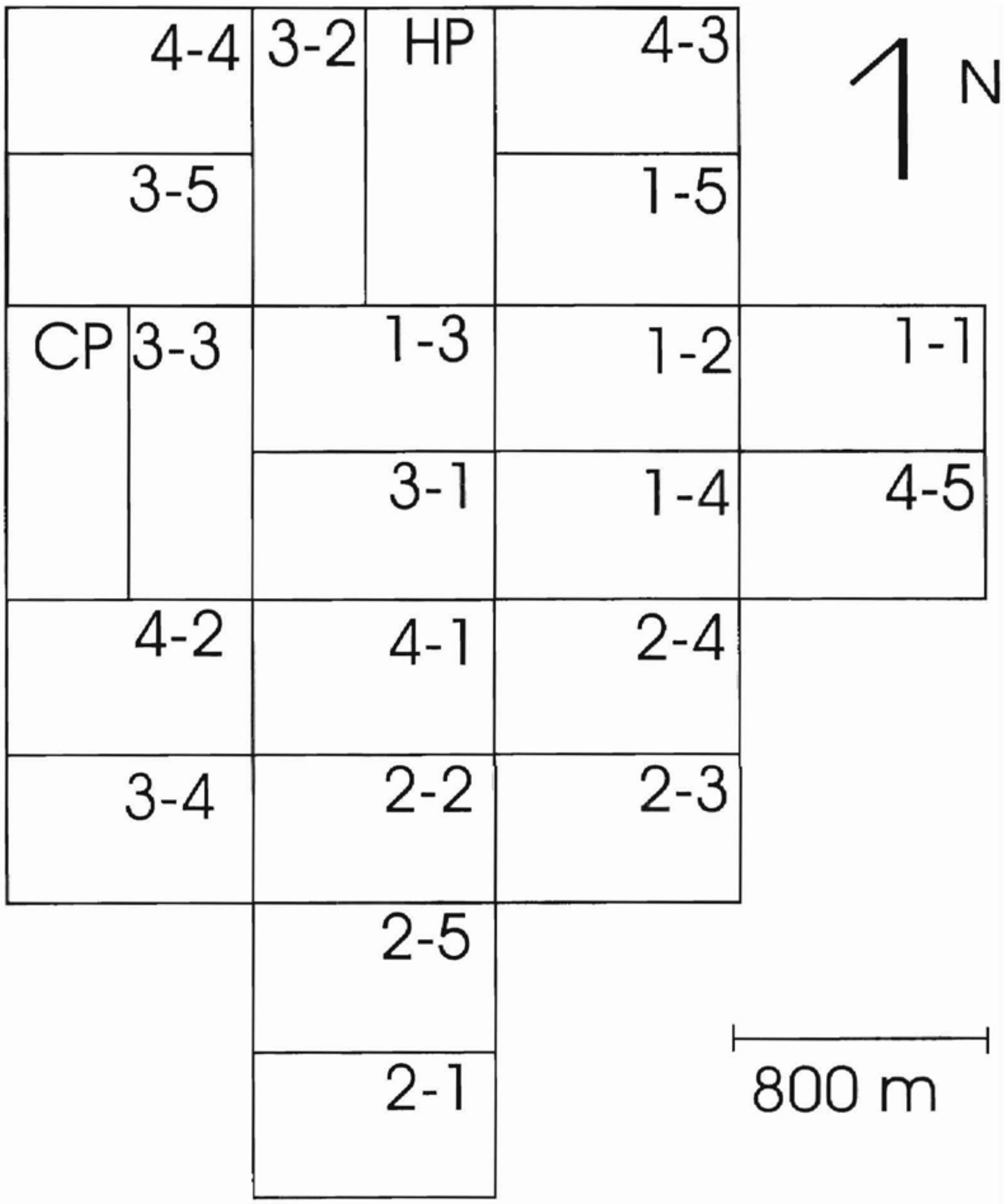

4-4
3-2
HP
4-3
N
3-5
1-5
CP
3-3
1-3
1-2
1-1
3-1
1-4
4-5
4-2
4-1
2-4
3-4
2-2
2-3
2-5
2-1
800 m

Figure I.2: Trapping grid for sample pasture used at Cross Timbers Experimental Range, Payne County, Oklahoma.

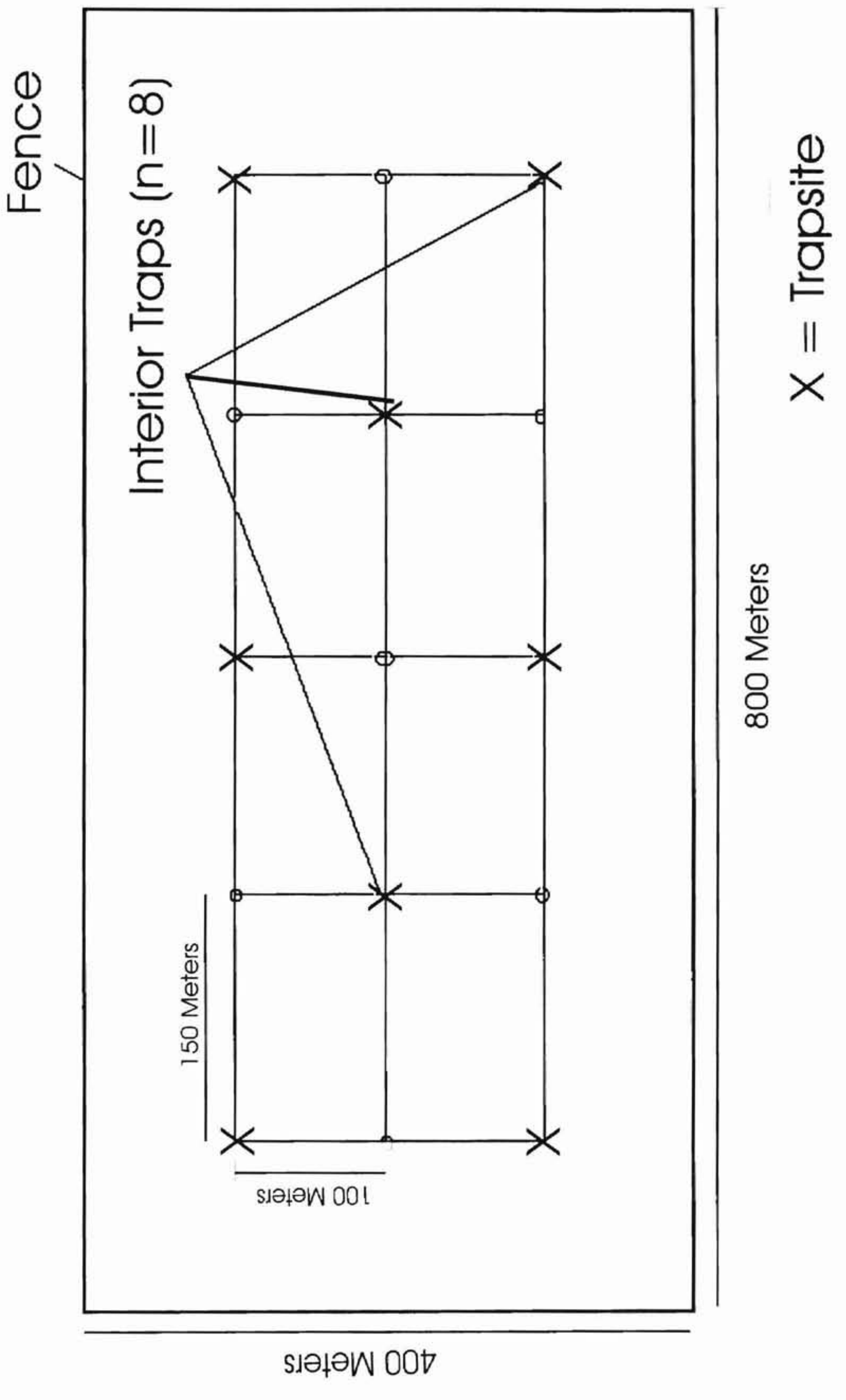

Fence
Interior Traps (n=8)
150 Meters
100 Meters
800 Meters
400 Meters
X = Trapsite

Figure I.3: Percent of captures by species and year at Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

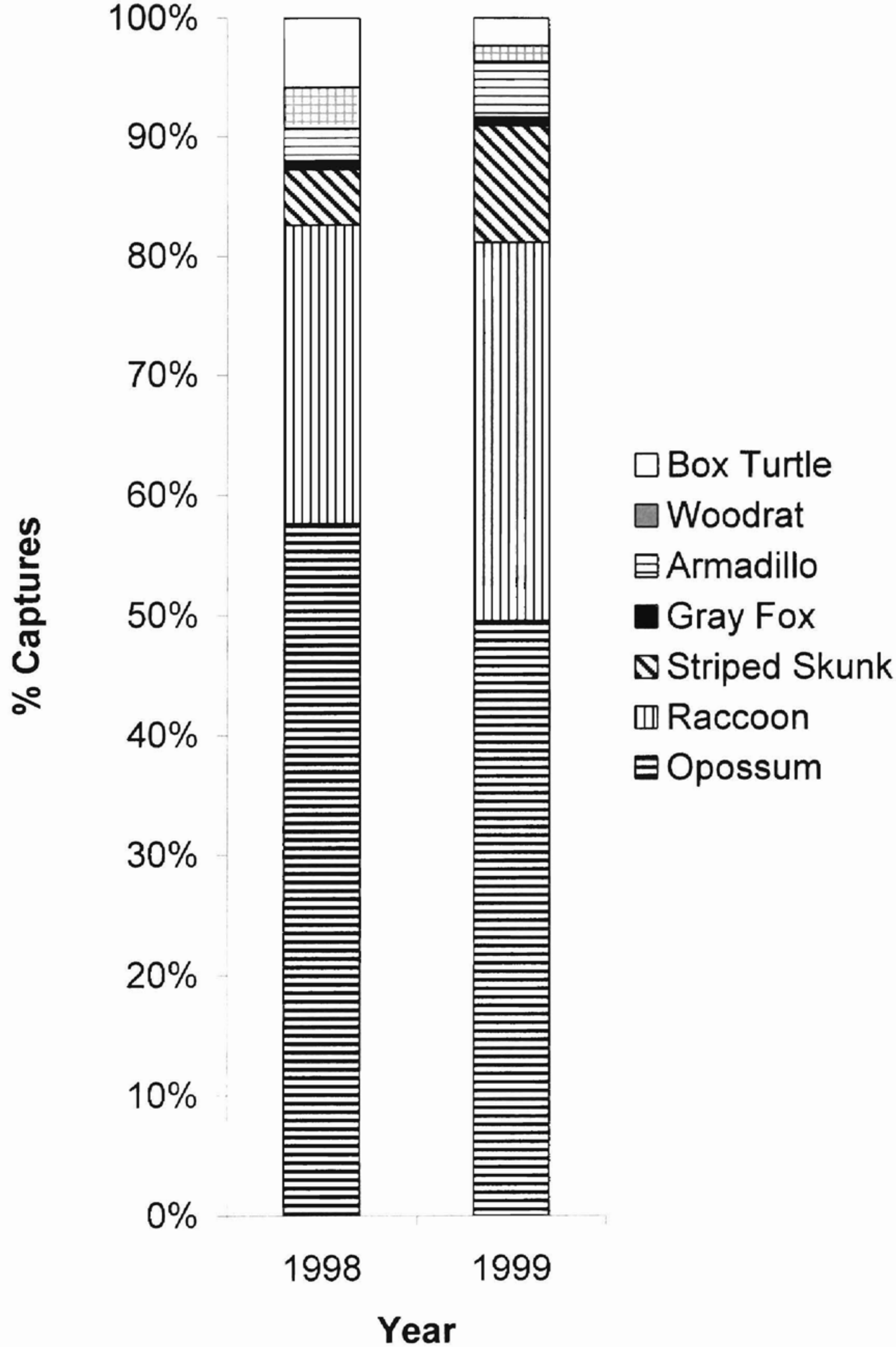
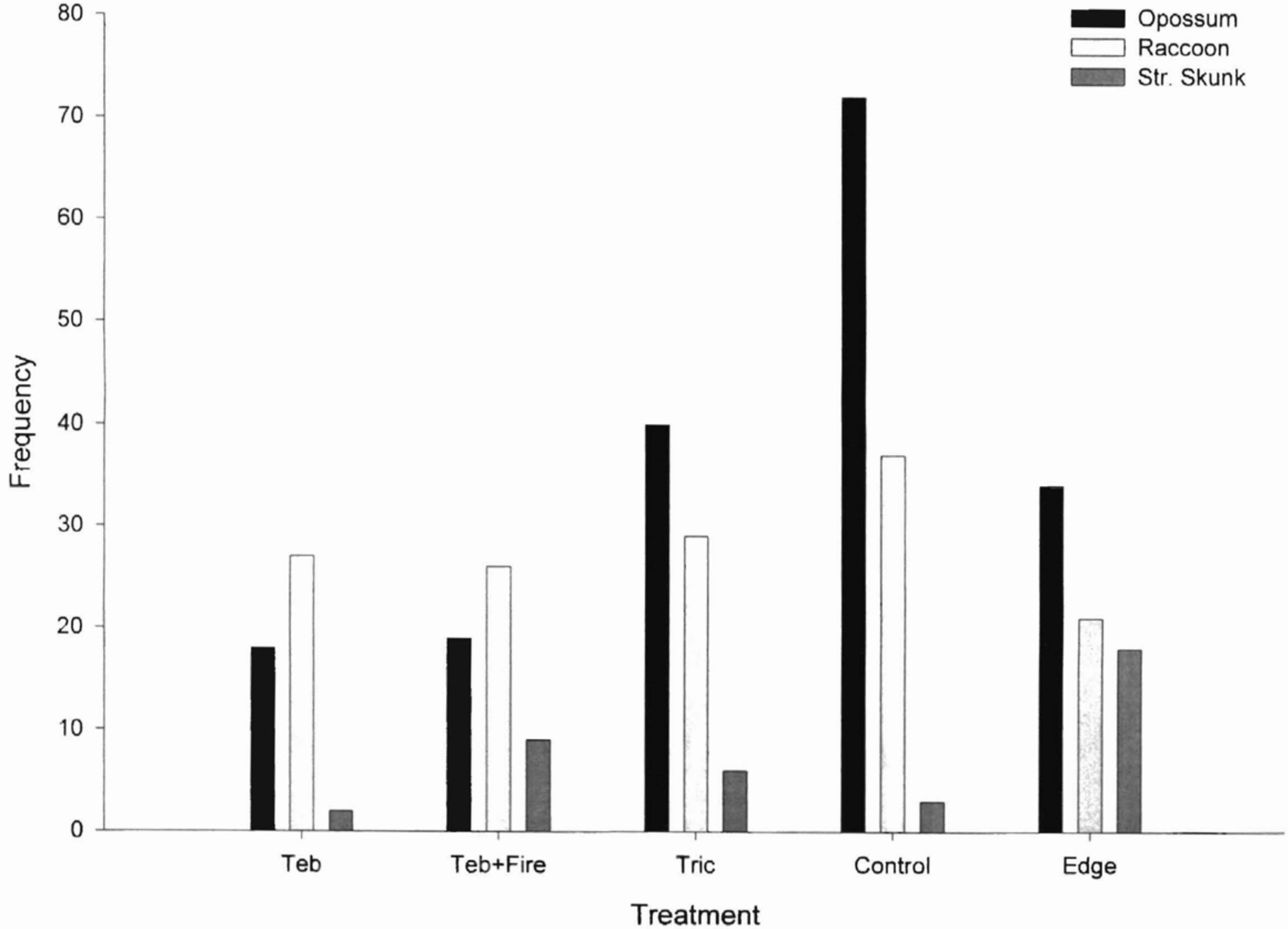
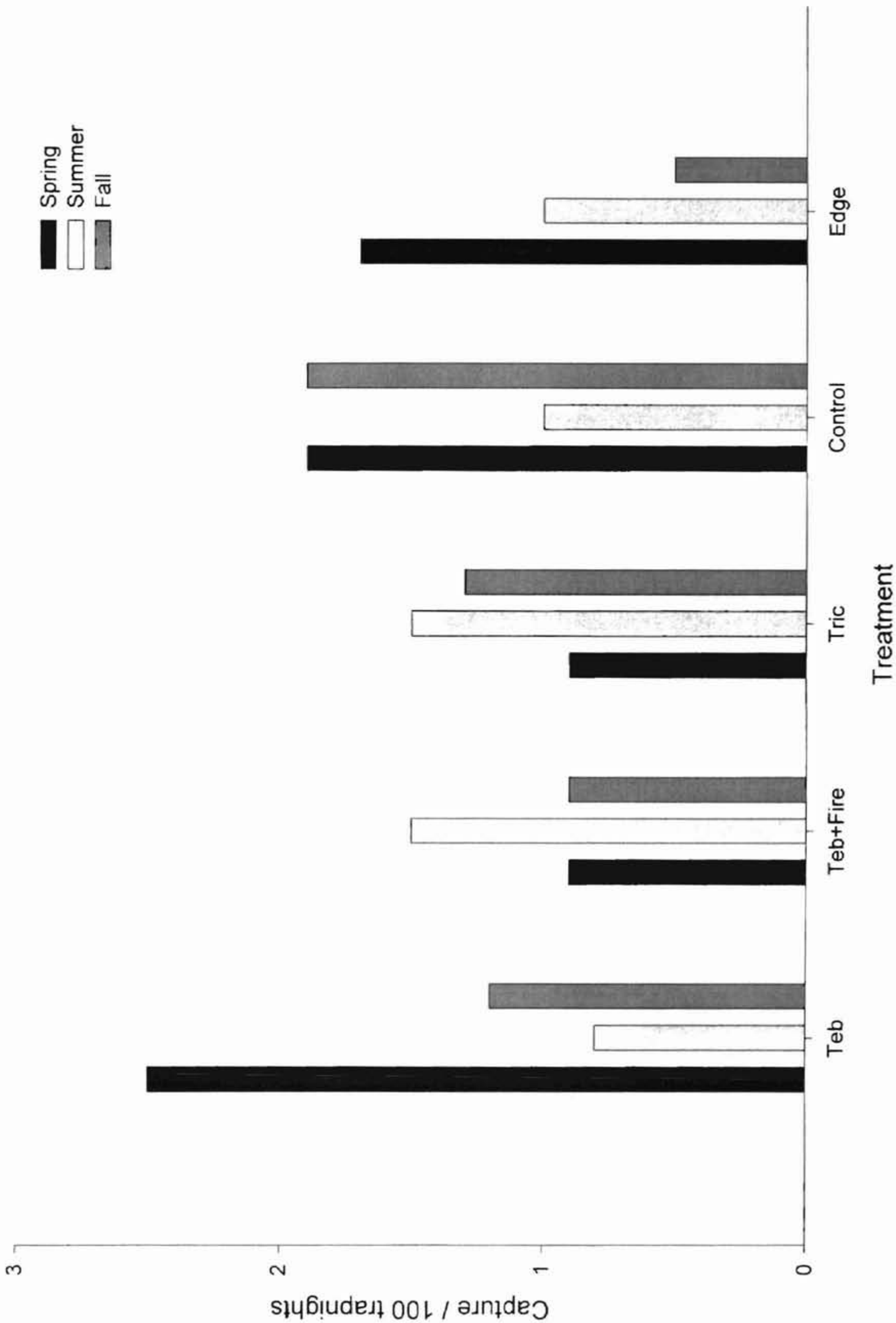

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
% Captures
1998
1999
Year
Box Turtle
Woodrat
Armadillo
Gray Fox
Striped Skunk
Raccoon
Opossum

Figure I.4: Total capture frequencies of opossums, raccoons, and striped skunks by treatment at Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999: Teb = Tebuthiuron; Teb+Fire = Tebuthiuron + prescribed fire; Tric = Triclopyr + recent prescribed fire; Control = No treatment; and Edge = Transition between treatments delineated by fenceline.



Opossum
Raccoon
Str. Skunk
Frequency
0
10
20
30
40
50
60
70
80
Teb
Teb+Fire
Tric
Control
Edge
Treatment

Figure I.5: Relative abundance of raccoons by season and treatment on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999: Teb = Tebuthiuron; Teb+Fire = Tebuthiuron + prescribed fire; Tric = Triclopyr + Recent prescribed fire; Control = No treatments; and Edge = Transition between treatments delineated by fenceline.



Spring
Summer
Fall
Capture / 100 trapnights
0
1
2
3
Teb
Teb+Fire
Tric
Control
Edge
Treatment

Figure I.6: Frequency of unique captures of opossums and raccoons by treatment on Cross Timbers Experimental Range, Payne County, Oklahoma: Teb = Tebuthiuron; Teb+Fire = Tebuthiuron + prescribed fire; Tric = Triclopyr + recent prescribed fire; Control = No treatment; and Edge = Transition between treatments delineated by fenceline.

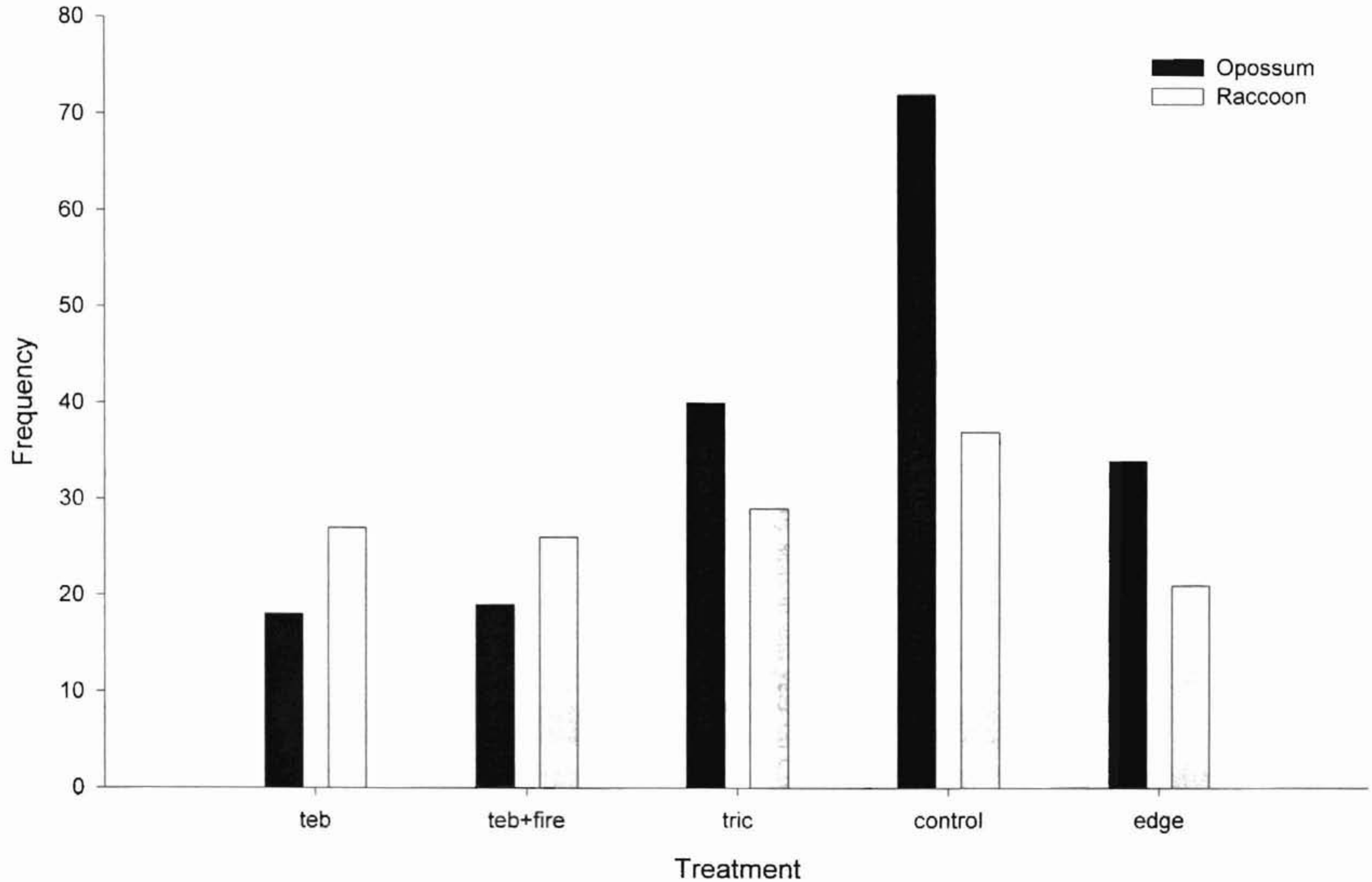

Opossum
Raccoon
80
70
60
50
40
30
20
10
0
Frequency
teb
teb+fire
tric
control
edge
Treatment

Figure I.7: Frequency of unique opossum captures by season and year on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

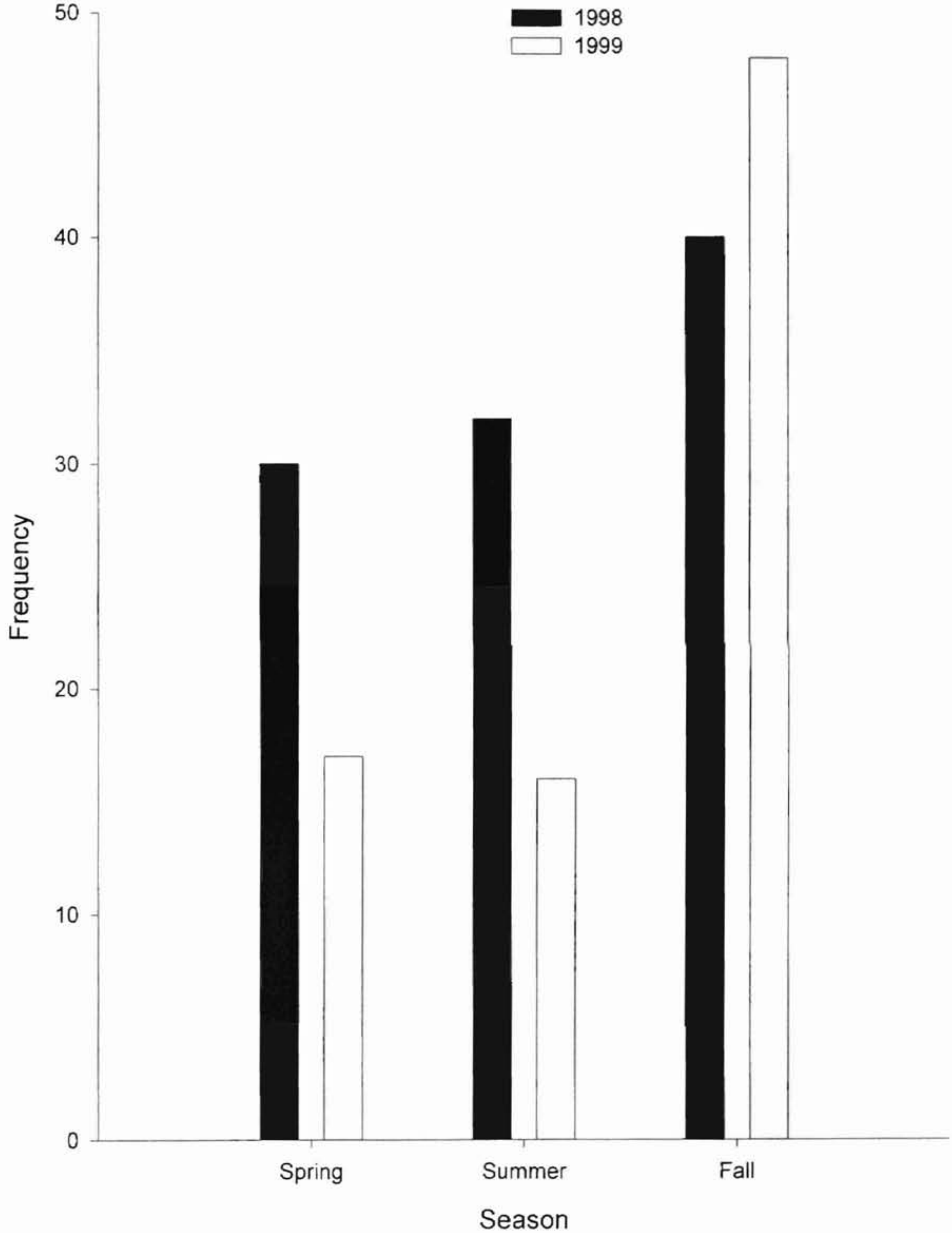
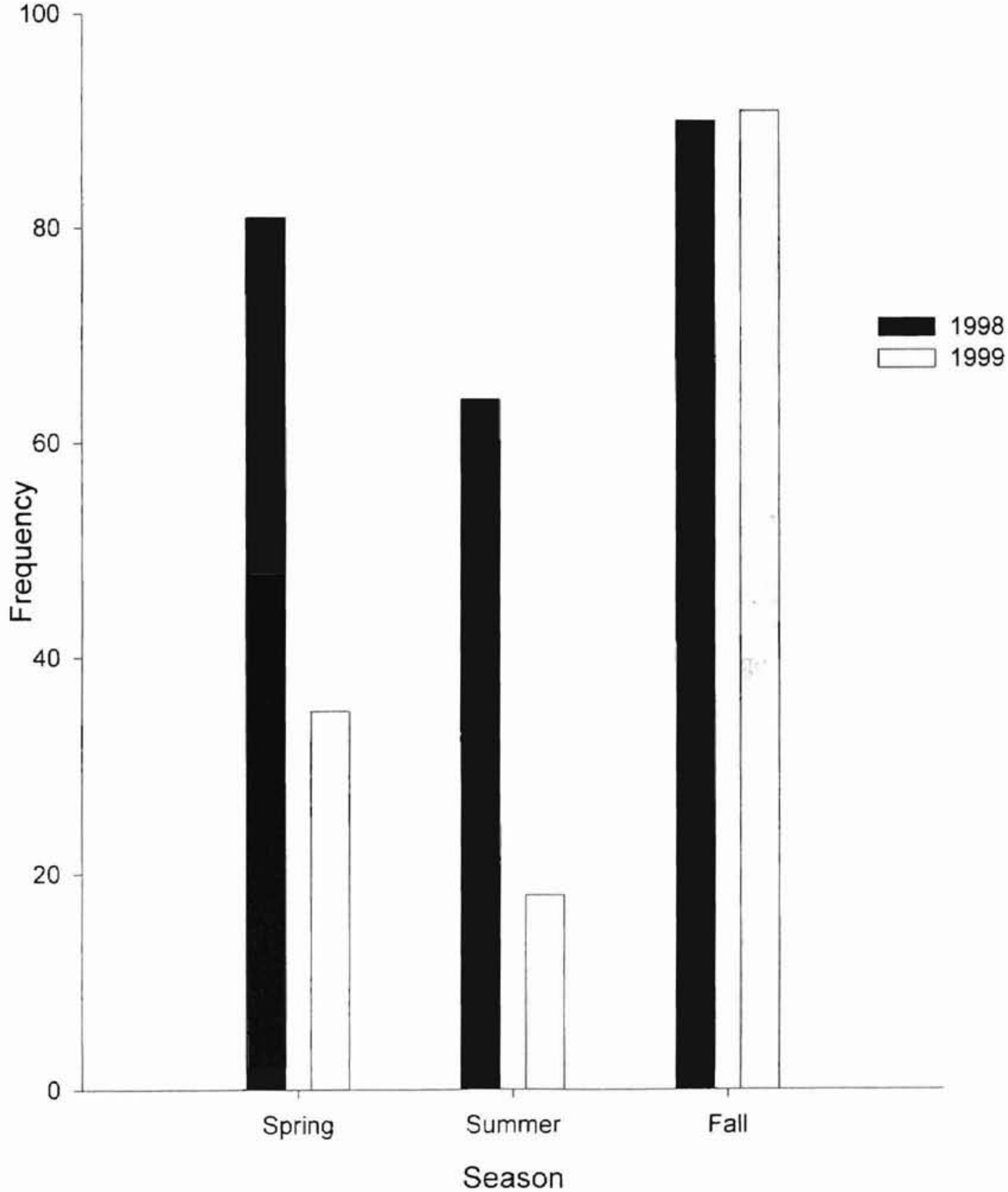
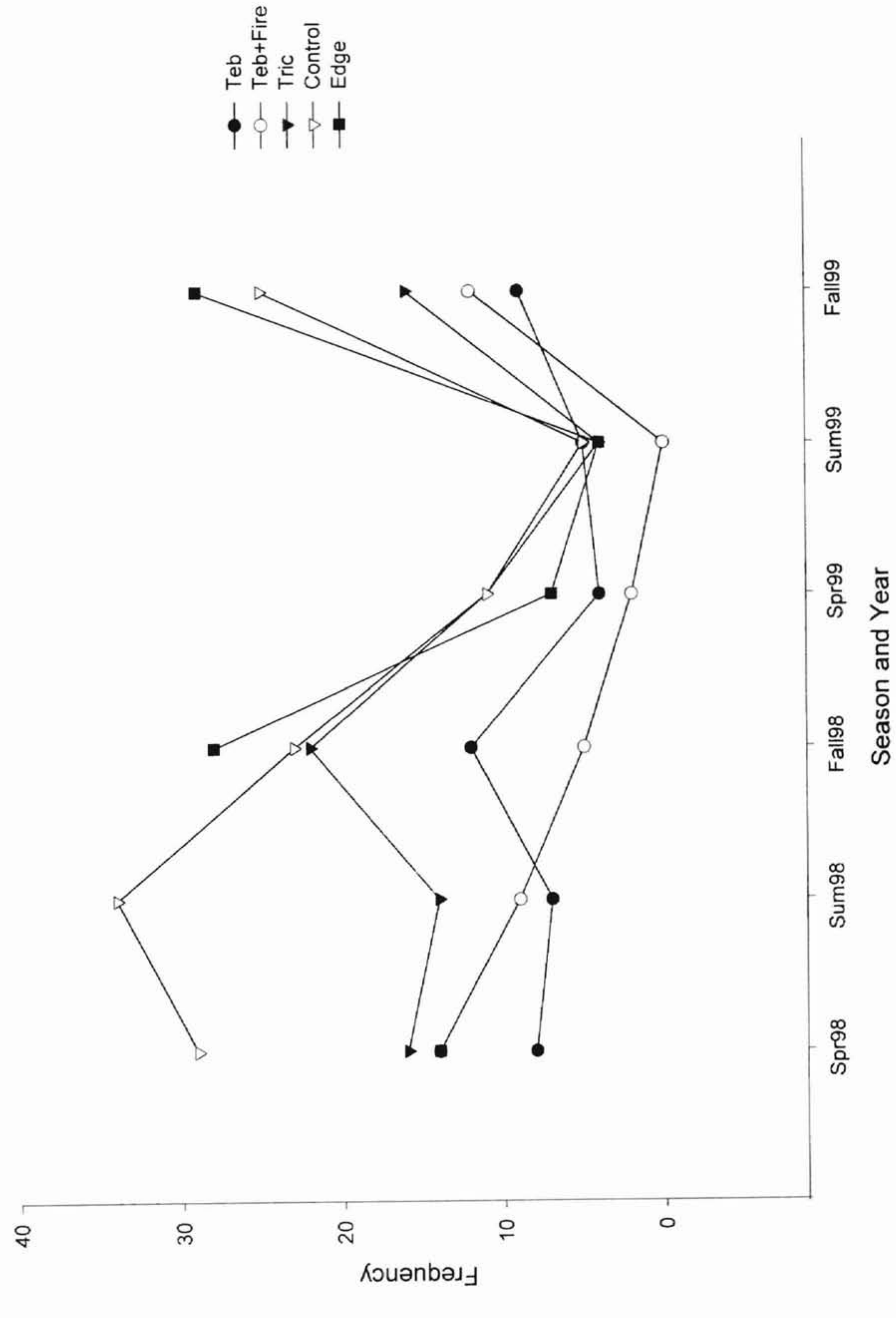

1998
1999
50
40
30
20
10
0
Frequency
Spring
Summer
Fall
Season

Figure I.8: Frequency of total opossum captures by season and year on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.



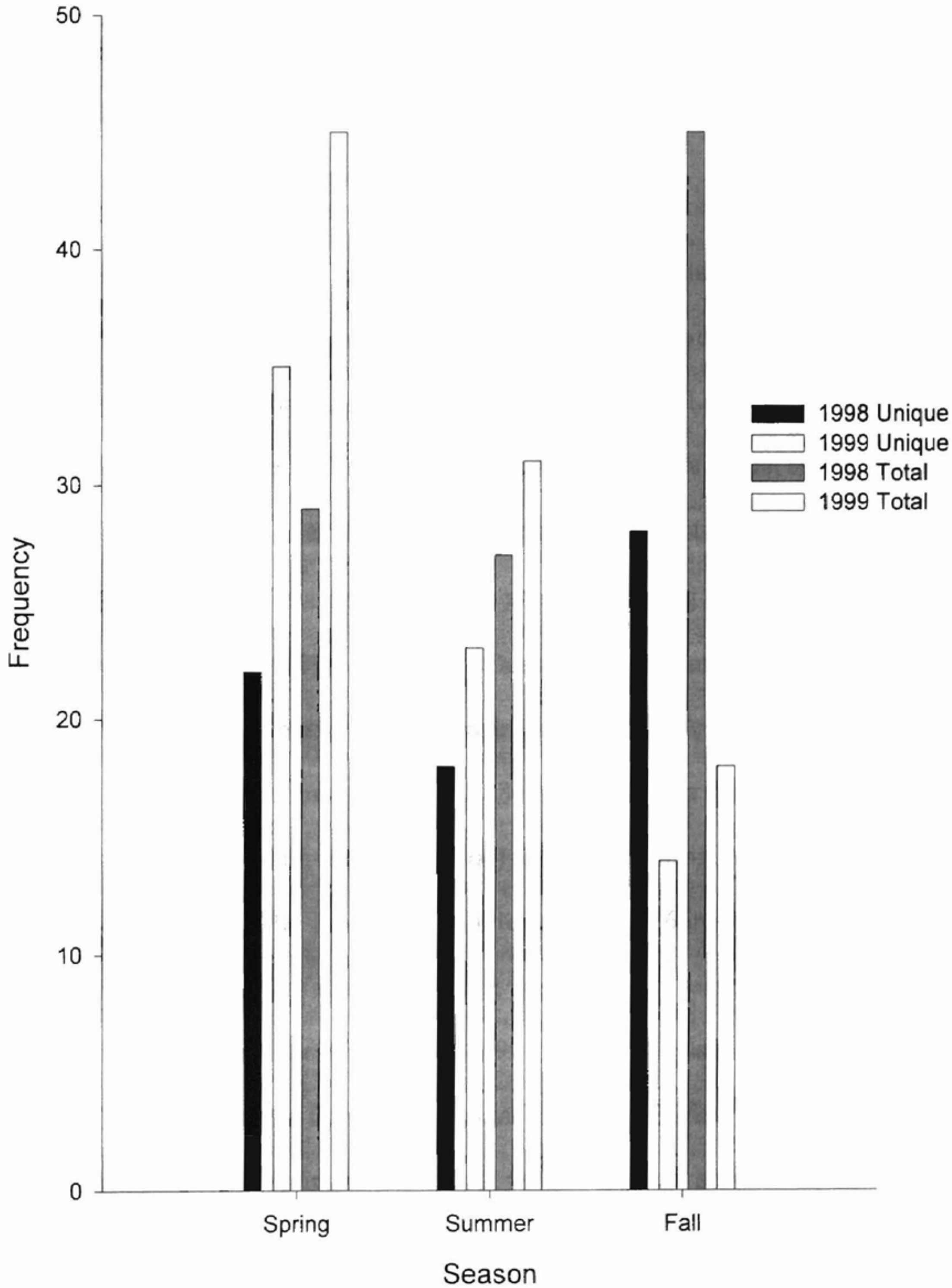
100
80
60
40
20
0
Frequency
1998
1999
Spring
Summer
Fall
Season

Figure I.9: Frequency of total opossum captures by season and treatment on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999: Teb = Tebuthiuron; Teb+Fire = Tebuthiuron + prescribed fire; Tric = Triclopyr + recent prescribed fire; Control = No treatment; and Edge = Transition between treatments delineated by fenceline.



Teb
Teb+Fire
Tric
Control
Edge
Frequency
0
10
20
30
40
Spr98
Sum98
Fall98
Spr99
Sum99
Fall99
Season and Year

Figure I.10: Frequency of unique and total raccoon captures by season on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.



50
40
30
20
10
0
Frequency
Spring
Summer
Fall
Season
1998 Unique
1999 Unique
1998 Total
1999 Total

CHAPTER II

DEMOGRAPHICS OF RACCOONS AND OPOSSUMS IN THE CROSS TIMBERS ECOREGION OF OKLAHOMA

ABSTRACT

Increases in mammalian mesocarnivores are a consequence of landscape fragmentation and loss of large carnivores. I studied demographics of Virginia opossums (*Didelphis virginiana*) and raccoons (*Procyon lotor*) in a managed Cross Timbers ecosystem in central Oklahoma using live-trapping. I made 381 captures of 145 opossums and 199 captures of 100 raccoons in 8,760 trap-nights during spring, summer, and fall of 1998 and 1999 in a 6.8-km^2 area. Population size was estimated using Jolly-Seber analysis. Adult opossum numbers were greatest in spring 1998 ($\bar{x} = 95 \pm 58.2$ SE) and lowest in summer 1998 (29 $\pm$ 6.4). Density of opossums ranged from 3.9 $\pm$ 0.9 / km^2 to 12.8 $\pm$ 7.8/km^2. Apparent survival rates (survival - emigration) of opossums calculated using mark-recapture data were 0.18-0.19 ($\pm$0.08) for spring-summer, 0.51-0.57 ($\pm$0.14) for summer-fall, and 0.07 ($\pm$0.04) for the fall-spring. Annual turnover of opossums was nearly 100%. Size of pouch litter averaged 6.6 in spring and 6.8 in summer, with 83 and 65% of females carrying young in these seasons, respectively. Raccoon numbers were highest in summer 1999 (125 $\pm$ 103.3) and lowest in spring 1999 (70 $\pm$ 23.3). Density ranged from 8.6 $\pm$ 2.9/km^2 to 15.3 $\pm$ 12.7/km^2. Proportion of adult raccoons decreased from spring to fall in both years. Apparent survival rates of raccoons were 0.49-0.60 ($\pm$0.14) for the spring-summer, 0.23-0.72 ($\pm$0.13) for summer-fall, and 0.72 ($\pm$0.14) for fall-spring. Demographics of opossums and raccoons in the Cross Timbers were similar to those in areas with similar habitat composition.

INTRODUCTION

Wildlife species are influenced in a variety of ways as humans expand further into native landscapes. Extirpation of large carnivores has been related closely to human population growth (Woodroffe 2000). Loss of large carnivores from an area removes a major limiting factor on populations of medium-sized (1-10 kg) mammalian carnivores, or mesocarnivores. The concept of mesocarnivore release has been around for decades (Fitch and Sandidge 1953) and recently has gained more notice for effects upon populations of songbirds (Rogers and Caro 1998, Crooks and Soule 1999) and lagomorphs (Palomares et al. 1995). Conversely, mesocarnivores may benefit not from release from larger carnivores but from increases in habitat heterogeneity (Oehler and Litvaitis 1996). Previous tracts of contiguous habitat are becoming a mosaic due to anthropogenic manipulations for a variety of purposes including ownership fragmentation (Boren et al. 1996), agriculture (Dijak and Thompson 2000), and timber harvest (Chamberlain et al. 1999).

The Virginia opossum (*Didelphis virginiana*) is the only native marsupial found north of Mexico and has been expanding its range in the last 100 years (Gardner 1982). The opossum thrives in anthropogenically disturbed areas because of its habitat-generalist nature and is primarily found in deciduous woodlands with high heterogeneity and stream associations (Gardner 1982). It is an *r*-selected species with high reproductive output and low annual survival. Because of these life-history traits, opossum demography is characterized by high population turnover and large variability in population density (Seidensticker et al. 1987, Gehrt et al.1997).

The raccoon (*Procyon lotor*) is a generalist that readily adapts to a variety of environments (Kaufmann 1982, Sanderson 1987). Raccoons are found in a diversity of habitats, often with stream association. They tend to avoid pine and open grassland areas (Chamberlain et al. 1999, Kaufmann 1982). Compared with opossums, raccoons are relatively K-selected with high annual survival and moderate reproductive output. Because of these traits, raccoon demography is characterized by longer life-span and more stable population trends (Kaufmann 1982, Sanderson 1987).

Ecological relationships of opossum and raccoon populations to landscape structure have received increased attention in recent years (Kissell and Kennedy 1992, Heske et al. 1999, Dijak and Thompson 2000); however, these studies provided little information about demographics. My objectives were to describe demographic characteristics and estimate density and survival of these species in a managed site in the Cross Timbers ecoregion of central Oklahoma. I predicted that demographic characteristics should be similar to those observed in studies in heterogeneous habitats and at comparable latitudes.

STUDY AREA

The Cross Timbers Experimental Range (CTER), owned by Oklahoma State University, has been used since 1983 to study vegetation management in the Cross Timbers (Engle et al. 1991, Stritkze et al 1991), livestock production (McCollum et al. 1987), and wildlife. CTER is located 11 km southwest of Stillwater, Payne County, OK (36°02'40" to 36°04'20"N, 97°09'30" to 97°11'39"W). The overstory is primarily post oak (*Quercus stellata* Wang.), blackjack oak (*Q. marilandica* Muench.), and American elm (*Ulmus americana* L.) interspersed with eastern redcedar. Little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], indiangrass [*Sorgahastum nutans* (L.)

Nash.], swithgrass *(Panicum virgatum* L.), grama grasses (*Bouteloua* spp.), purpletop [*Tridens flavus* (L.) Hitchc.], ragweed (*Ambrosia* spp.), and buckbrush (*Symphoricarpos orbiculatus* Moench.) are prevalent in the understory (Ewing et al. 1984).

The land-use history of CTER started as homestead and private cultivation of crops such as cotton (Ewing et al. 1984). In 1983, a regime of herbicide, fire, and combinations of each was prescribed to examine ecosystem response in 32-ha treatments. The area now encompasses 712 ha comprising 22, 32.4-ha pastures (Fig. 1). Pastures have undergone different treatment regimes, producing a landscape mosaic of habitat types. The CTER comprise 5 experimental treatments randomly assigned within 4 replicate groups blocked by soil type and original total woody canopy cover. Treatments were tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N`-dimethylurea, Dow Elanco, Indianapolis, Indiana, USA) applied aerially at 2.2 kg/ ha in March 1983; tebuthiuron with prescribed burning; triclopyr ([(3,5,6-trichlor-2-pyridinyl)oxy]acetic acid, Dow Elanco) applied aerially at 2.2 kg/ha in June 1983; and triclopyr with prescribed burning; and control (no herbicide or burning; Table 1). The triclopyr alone treatment was supplemented with prescribed fire starting in 1996 on a 3-year cycle.

Tebuthiuron is a soil-applied herbicide absorbed through root systems. Application at CTER resulted in die-off of most woody species, thereby allowing eastern redcedar to become established. Triclopyr is a foliar-applied herbicide absorbed through the leaf surface that primarily kills broadleaf species including deciduous woody plants. When aerially applied, it allows release of understory woody species if the overstory is sufficiently dense to intercept the herbicide. When either herbicide treatment is combined with a spring headfire regime, remaining woody species are reduced (Engle et al. 1991, Stritzke et al. 1991). Four derived habitat types resulted from treatments applied (D.M. Engle, *personal communication*): eastern redcedar forest, derived grassland, brush-grassland community, and mature oak forest (Tables 1, 2).

METHODS

Experimental Design and Sampling

Four of the 5 experimental treatments were sampled. Pastures treated with tebuthiuron only, tebuthiuron-and-fire, triclopyr-and-recent-fire, and control pastures were chosen. Triclopyr-and-fire produced a derived grassland habitat similar to the tebuthiuron-and-burning treatment and was not sampled. Edges between treated pastures were sampled as a separate treatment. There were 4 replicates of each treatment except for the tebuthiuron treatment, which lost a replicate to a crown fire that burned most of the pasture in 1996.

Trapping was conducted seasonally in 1998 and 1999, with 4 consecutive 10-day trapping periods (1 period/replicate/season). Seasons were defined as spring (Apr-May), summer (Jul-Aug), and fall (Sep-Nov). In pasture interiors, trapping grids were set up in a variation of a 3 x 5 grid for a total of 8 traps (Fig. 2, Chapter 1). Traps were located 100-m from the edges of the pasture to diminish edge effects. Traps were located 300-m apart along parallel transects spaced at 200-m intervals, and there was 2 interior plots 180-m diagonally from the corners (Fig. 2, Chapter 1). Edges were trapped along the long axis of the pastures starting 200-m from a pasture corner with traps placed every 200-m. Eight edge traps were used in each 10-day trapping period to equalize representation among pastures. Due to a limited number of traps, edge areas were not trapped during summer 1998. Traps were checked daily.

Animals were sampled using Tomahawk (Tomahawk Trap Company, Tomahawk, Wisconsin, USA) wire-mesh traps (25 x 31 x 81 cm) baited with sardines. Animals were identified by species, anesthetized with Telazol (tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Supply, Fort Dodge, Iowa, USA) at 8 mg / kg estimated body mass, ear-tagged with #4 Monel tags (National Band and Tag, Newport, Kentucky, USA), sexed, aged (adult, juvenile), and weighed (kg) with a spring scale (Chatillon Scale Company, New York, New York, USA). Total, tail, hindfoot, ear, and canine lengths were recorded on the left side to the nearest 1.0 mm with a flexible tape. Animal location was recorded as a replicate–treatment code combination and trap-site number. If an animal had been captured already in a 10-day trapping session, it was released following recording of species, ear-tag number, and location. If the animals had been captured before, but not during, the current trapping season, then the animal was handled in the same manner as a new capture.

Analysis

Sex (F:M) and age (Ad:Juv) ratios were analyzed using log-linear analysis (PROC CATMOD, SAS Institute Inc. 1990) to explore effects of species (raccoon, opossum), season, year, and all interactions. That technique analyzed frequency data and permited evaluation of interactions among $\geq$2 main effects. Based upon data availability, sex ratios were analyzed for adult opossums and raccoons. Age ratio analysis was conducted for summer and fall only because no juvenile opossums were available in spring.

Reproductive data collected for opossums included number of females with young and number of young in the marsupium. Litter size was compared among seasons with a 1-

way ANOVA. Data on proportion of females with young in marsupium are presented descriptively.

Standard Cormack-Jolly-Seber (CJS) live-recaptures model in Program MARK (White and Burnham 1999) was used to estimate apparent survival (ϕ) and capture probability (p) of raccoons and opossums separately from capture-recapture data (Lebreton et al. 1992). Apparent survival was a combination of resident survival and emigration and thus was an estimate of 1.0-disappearance. The 4 assumptions of the open population model were that (1) marks were not lost or overlooked; (2) samples were instantaneous and releases were made immediately after the sample; (3) every animal in the population at the time of the ith sample had the same probability of capture; and (4) every marked animal in the population immediately after the ith sample had the same probability of survival until the $(I + 1)$th sample (Pollock et al. 1990). I believe that assumptions 1 (marks not lost) and 2 (immediate release) were met. I used goodness-of-fit tests in program RELEASE (Version 3.0 embedded in Program MARK; Burnham et al. 1987) to test assumptions 3 and 4, which were related to capture homogeneity and behavioral response to capture. The global model included effects for time (trapping interval) and age variation in ϕ and p. Model notation followed Lebreton et al. (1992), with subscripts for ϕ and p being t for time and a for age. Progressively simpler models were fit and model selection was based on log-likelihood ratio tests and Akaike's Information Criteria (AIC; Burnham and Anderson 1992) following methods outlines and exemplified by Lebreton et al. (1992). Briefly, I selected the most parsimonious model based on minimization of the AIC and a small number of likelihood-ratio tests for specific hypotheses. Survival estimates for the last trapping interval were estimated as

ϕ_5/p because estimates for the last period of ϕ and p were confounded (Lebreton et al. 1992:75).

Population estimates for opossums and raccoons were estimated for each trapping session using Chapman's version of Lincoln-Peterson index for closed populations (Lancia et al. 1994). Estimates were made for spring, summer, and fall 1998 and spring and summer 1999 for raccoons and opossums. However, the opossum estimate in fall 1998 was for juveniles only, because no adult opossums were both captured in 1998 and recaptured in 1999. I assumed emigration was equal to immigration and no difference in survival of marked and unmarked animals. I calculated density following Wilson and Anderson (1985), adding a buffer of one-half the maximum distance moved (based on recaptures) to the core trapping area (3.47 km^2) to estimate effective trapping area. Population estimates were divided by effective trapping area to obtain opossum and raccoon densities.

RESULTS

Sex and Age Structure

I captured 145 opossums 381 times and 100 raccoons 199 times during the study. Sex ratios varied by a species-by-season interaction ($\chi^2_2 = 13.24$, $P = 0.013$; Fig. 1). Sex ratio of adult opossums was close to parity (1.00F : 1.02M; $n = 119$) but varied during the study (Fig. 3). The most female-biased sex ratios of opossums were in summer 1999 (1.0F:0.38M), and spring 1999 (1.0F:2.0M). The cumulative sex ratio (summed across the duration of the study) of raccoons favored males (1.00F: 1.34M, $n = 103$), but females outnumbered males in summer (1.0F: 0.55M) and fall 1998 (1.0F: 0.91M).

Age ratios tended to vary as a function of an interaction of species with year and age ($\chi^2_1 = 3.35$, $P = 0.067$). Opossum age ratios were closer to parity than raccoons (Fig. 2). In both species, the ratio of adults to nonadults declined from summer to fall (except for opossums in fall 1998) as recruits entered the trappable population (Fig. 2).

Reproduction

Average ($\pm$ SE) litter size of opossums was 6.8 $\pm$ 0.3 (n=27), with no variation across seasons ($F_{3,23} = 0.14$, $P = 0.93$). Average litter size ranged from 7.2 $\pm$ 1.7 (n = 6) in summer 1998 to 6.1 $\pm$ 1.4 (n = 9) in spring 1998. No young were found in the marsupium during autumn. Across years, proportions of female opossums with young were 0.76 in spring (19/25) and 0.42 in summer (11/26). Pouch young were rarely found in August, and none in fall of either year.

Population Estimation and Density

Opossum population estimates varied during the study. Spring 1998 had the highest adult population estimate of 95 $\pm$ 58.2, whereas summer 1998 was the lowest at 29 $\pm$ 6.4 individuals. Spring and summer 1999 were intermediate at 76 $\pm$ 59.3 and 51 $\pm$ 19.9 adult individuals, respectively. I estimated 127 $\pm$ 105.3 juveniles in fall 1998.

The maximum 24-hour distance moved by an opossum on CTER was 450 m. An effective trapping area of 7.43 km^2 was estimated for opossums. Adult opossum density was highest in spring 1998 at 12.8 $\pm$ 7.8/km^2 and summer 1998 was lowest at 3.9 $\pm$ 0.9/km^2 (Fig. 3). A density estimate of 17 $\pm$ 14.2/km^2 was made for juvenile opossums in fall 1998.

Raccoon population estimates were less variable than opossums across trapping seasons. Population estimates of raccoons were 88 $\pm$ 36.1 in spring 1998; 84 $\pm$ 38.9 in summer 1998; 75 ± 20.2 in fall 1998; 70 ± 23.3 in spring 1999; and 125 ± 103.3 in summer 1999. The estimate in summer 1999 was likely high and imprecise because of only 2 recaptures between summer and fall 1999.

The maximum distance moved for raccoons was 530 m, leading to an effective trapping area of 8.16 km^2. Density estimates ranged from 15.3 ± 12.7/km^2 in summer 1999 to 8.6 ± 2.9/km^2 in spring 1999 (Fig. 3)

Survival and Capture Probability

Model selection led to a model (ϕ_t, *p*.) in which apparent survival varied by intervals for each species, but capture probability remained constant. Opossum capture probability was 0.84 ± 0.14, whereas raccoon capture probability was 0.51 ± 0.09.

Apparent survival rates varied between trapping intervals for opossums and raccoons. For opossums, survival was highest from summer to fall (1998: 0.59 ± 0.12; 1999: 0.56. ± 0.15). The estimate for survival from spring to summer was moderate and similar between years (1998: 0.18 ± 0.07; 1999: 0.18 ± 0.09). Overwinter survival was the lowest for any interval (0.07 ± 0.04). Of 102 opossums captured in 1998, only 3 juvenile males caught in the fall were recaptured the following year.

Survival estimates for raccoons were higher than for opossums. Survival was highest for the interval from summer to fall 1998 (0.72 ± 0.15) and fall 1998 to spring 1999 (0.72 ± 0.14). Survival estimate for the spring to summer 1998 interval were intermediate (0.60 ± 0.14), whereas spring to summer 1999 (0.49 ± 0.13) and summer to fall 1999 (0.46 ± 0.14) estimates were lowest. Although the over-winter survival estimate was high, only 8 of 68 raccoons captured in 1998 were captured in 1999.

DISCUSSION

Demographics of mesocarnivores in this mosaic of the Cross Timbers were similar to those in other areas with a similar habitat composition or at a similar latitude (Sanderson 1987, Seidensticker at al. 1987). High reproductive output and low survival, typical of an *r*-selected life-history, characterized opossums. Raccoons had higher survival with higher proportion of adults, which is consistent for K-selected species (Smith 1986).

Opossum sex ratios reported in the literature vary. Fitch and Sandidge (1953) found about 1M:1F in heterogeneous habitat in Kansas, whereas Seidensticker et al. (1987) reported a male-biased population in similarly fragmented habitat in Virginia. Conversely, Holmes and Sanderson (1965) found a female-biased sex ratio in hardwood dominated habitat with grassland in Illinois. The evenness in sex ratio on CTER could be from a lack of intersexual preference or avoidance of traps by opossums. The increase in the number of female opossums during summer could be due to increased movements because young have become independent, thereby increasing capture potential, or high adult male mortality. Age ratios on CTER corresponded with ratios in similar geographic regions, with high juvenile recruitment in fall (Fitch and Sandidge 1953, Holmes and Sanderson 1964, Stout and Sonenshine 1974, Seidensticker et al. 1987).

Raccoon sex ratios on CTER were similar to previous work in other areas (Kaufmann 1982, Sanderson 1987). Several studies (Dellinger 1954, Sonenshine and Winslow 1972, Moore and Kennedy 1985) have reported male-biased sex ratios. However, Wood (1955) found 0.925M: 1.0F in the post-oak region of Texas. Gehrt and Fritzell (1996) found male-biased probability of capture. They attributed this to larger male home ranges, movement patterns, and intersexual differences regarding trap response. Non-adults are reported to compose <40% of raccoon populations (Sonenshine and Winslow 1972, Johnson 1970), which was consistent with results on CTER.

Opossum reproduction follows a geographic trend, with larger litter sizes in northern latitudes (Gardner 1982). Mean litter size in CTER was similar to those reported for opossums in Louisiana (6.8; Edmunds et al. 1978); Texas (6.8; Lay 1942); and Kansas (7.4; Fitch and Sandidge 1953).

Densities of opossums on CTER were similar to studies in comparable habitat mosaics and at similar latitudes (Table 2). It appears that opossum density is highest in hardwood-open habitat mixtures. Reported raccoon densities are more variable than opossums (Table 3), with highest densities in areas with wetland habitats. My results on CTER were similar to those in heterogeneous forest-old field mixtures (Sonenshine and Winslow 1972).

Low annual survival is characteristic of opossums (Gardner 1982, Seidensticker et al. 1987). Apparent annual survival, which is a combination of adult survival and juvenile survival, was calculated from seasonal interval estimates to be 0.007. Petrides (1949) reported an average opossum life span of 1.3 years and few studies found longevity >18 months. Gillette (1980) reported that none of 92 opossums survived to 1 year of age, and Lay (1942) found only 1 opossum out of 56 that lived >11 months post-capture. Llewellyn and Dale (1964) had only 3% >1 year of age in Maryland, and Gehrt et al. (1997) found that 4% of the population survived $\geq$12 months past first capture in Texas. Seidensticker et al. (1987) only had 8% of females and 5% of males survive 1 year after original capture in Virginia. Adults on CTER from spring to fall are likely recruits from the previous year.

Raccoon survival was much higher than opossum survival on CTER. This finding is also consistent with survival and longevity reported in the literature. Johnson (1970) reported 3.1 years to be the average age of raccoons in Alabama. In Iowa, Clark et al. (1989) obtained annual survival estimates of 0.47-0.75. In my study, apparent annual survival calculated using seasonal interval estimates was 0.31, considerably lower that previous estimates for both harvested (males 0.63; females 0.50; Chamberlain et al. 1999) and unharvested (0.84; Gehrt and Fritzell 1999) populations. This difference likely resulted from different methodology to calculate survival. Chamberlain et al. (1999) and Gehrt et al. (1999) used radiotelemetry to estimate survival, whereas I did not. Dispersal of raccoons from CTER and a high probability that marked raccoons were not on the trapping gird may account for the lower estimate.

Anthropogenic disturbance of habitat likely increases suitability for both opossums and raccoons. It appears that habitat heterogeneity affects opossums and raccoons at CTER in a manner similar to other populations of opossums and raccoons in their respective ranges. Using indices, Dijak and Thompson (2000) stated that opossums were more abundant in heterogeneous habitats with riparian associations. Dijak and Thompson (2000) also stated that raccoon numbers would be higher in heterogeneous habitats, which was in general agreement with the findings of Pedlar et al. (1997). However, further investigation into the relationship between the scale of fragmentation and mesocarnivore demography is necessary to better understand these effects. For example, opossums prefer mature oak forest on CTER (Chapter 1, 3), yet densities on the entire heterogeneous CTER area were higher than in homogeneous oak forest (Kissell and Kennedy 1992).

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Table II.1. Timing of treatment regime at Cross Timbers Experimental Range, Payne County , Oklahoma.

Treatment	Treatment regime: Herbicide	Burn	Mechanical	Current Habitat[a]
1	Tebuthiuron 1983	None	None	Cedar forest
2	Tebuthiuron 1983; P+D[b] 1997	1985, 86, 87, 90, 93, 96, 99	None	Derived Grassland
3	Triclopyr 1983; 2,4-D 1988; P+D[b] 1994, 1997	1993, 96, 99	Bulldoze and windrow cedar pre- 1996; saw cedar post-1996	Scrub- shrub forest
5	None	None	None	Mature oak forest

[a] D. M. Engle, pers. comm.

[b] picloram + 2,4-D

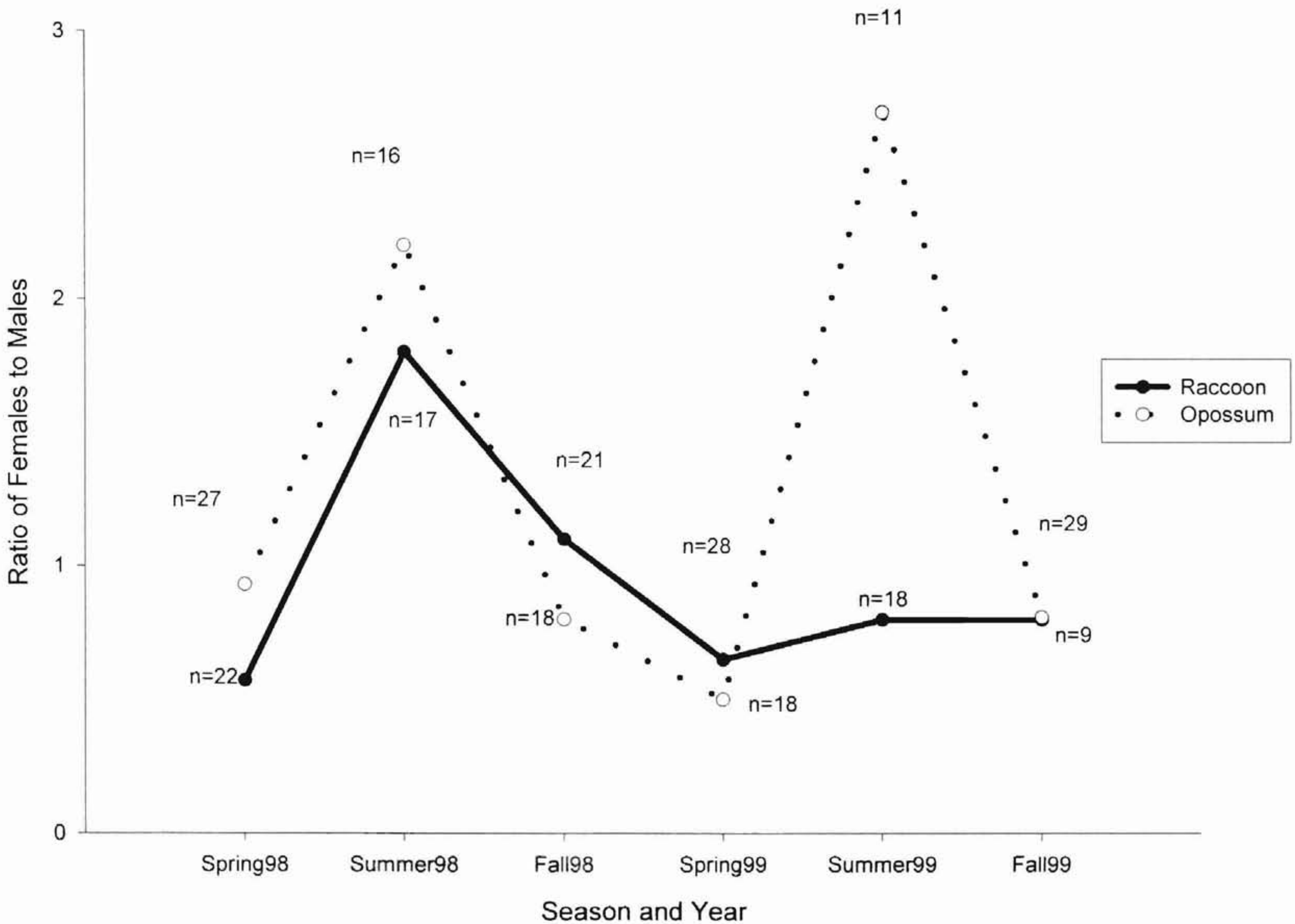
Table II.2. Reported densities of opossums from different latitudes and habitat compositions.

Density (#/km^2)	Latitude (°N)	Habitat composition	Study
1.1-6.8	28°6'	Mesquite grassland and chaparral grassland	Gehrt and Fritzell 1997
2.2	36°	Hardwoods only	Kissell and Kennedy 1992
3.9	39°	2nd growth forest, thickets, fields	Seidensticker et al. 1987
3.9-17.0	36°	Oak, cedar, and scrub forest and grassland	This study
6	30°	Coastal pine-hardwoods	Lay 1942
6.2-12.3	39°	Hardwood, pasture, and thickets	Fitch and Sandidge 1953
6.4	35°30'	Pine interspersed with hardwoods, crops	Leberg et al. 1983
10.1	36°	Hardwoods, pasture, and pine mix	Kissell and Kennedy 1992

Table II.3. Reported densities of raccoons from different latitudes and habitat compositions.

Density (#/km^2)	Latitude ($^{\circ}$N)	Habitat composition	Study
0.5-1.0	$47^{\circ}15'$	Prairie	Fritzell 1978
1.4	36°	Hardwoods, pasture, & pine mix	Kissell and Kennedy 1992
2.9	36°	Hardwoods only	Kissell and Kennedy 1992
4.0-12.3	28°	Mesquite grassland and chaparral grassland	Gehrt 1994
8.6-15.3	36°	Oak, cedar, and scrub forest and grassland	This study
17.3	37°	Mixed forest, old field, & swamp	Sonenshine and Winslow 1972
17.4	$41^{\circ}30'$	Waterfowl marsh	Urban 1970
49	$32^{\circ}30'$	Beaver swamp	Johnson 1970

Fig. II.1: Ratio of adult female to male opossums and raccoons during spring, summer, and fall 1998-1999 on the Cross Timbers Experimental Range, Payne County, Oklahoma.



Ratio of Females to Males
Season and Year
Spring98
Summer98
Fall98
Spring99
Summer99
Fall99
Raccoon
Opossum
n=27
n=22
n=16
n=17
n=21
n=18
n=28
n=18
n=11
n=18
n=29
n=9

Fig. II.2: Age ratio of opossums and raccoon during summer and fall, 1998-1999 on the Cross Timbers Experimental Range, Payne County, Oklahoma.

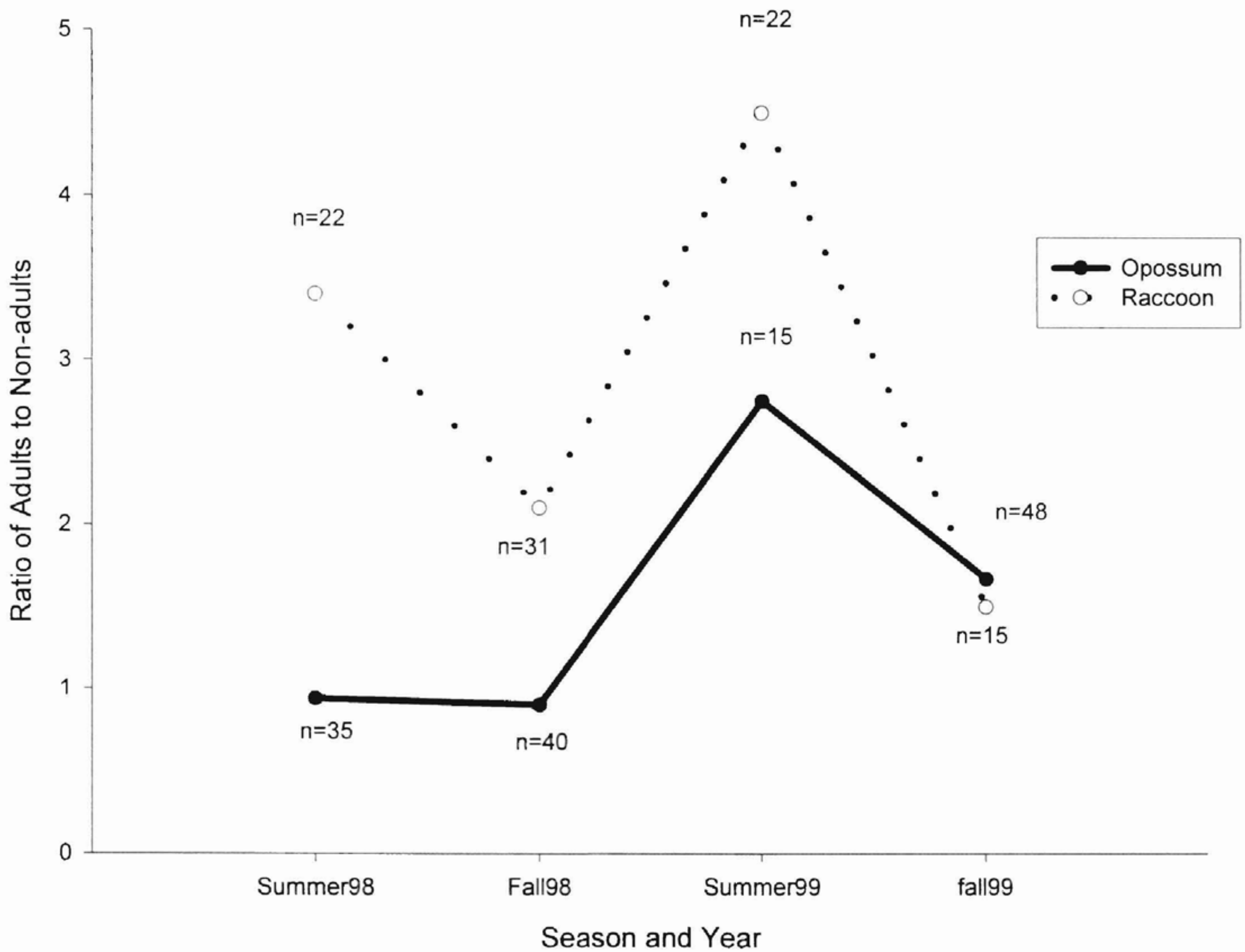
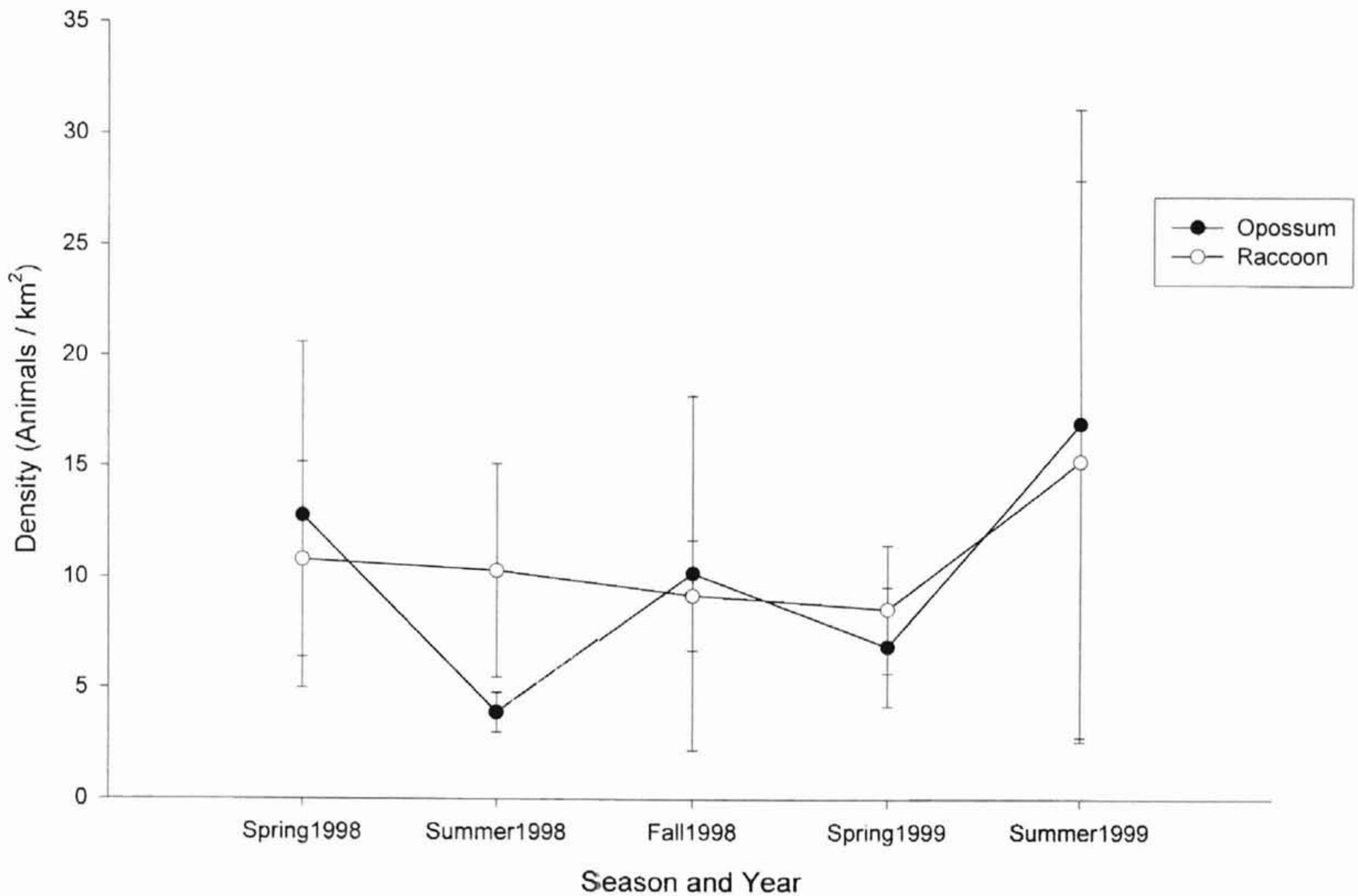

Ratio of Adults to Non-adults
Season and Year
0
1
2
3
4
5
Summer98
Fall98
Summer99
fall99
Opossum
Raccoon
n=22
n=31
n=22
n=48
n=35
n=40
n=15
n=15

Fig. II.3: Density estimates (number / km^2) of opossums and raccoon during spring, summer, and fall 1998 and spring and summer 1999 on the Cross Timbers Experimental Range, Payne County, Oklahoma. Fall 1998 opossum density estimate is for juveniles.


35
30
25
20
15
10
5
0
Density (Animals / km2)
Opossum
Raccoon
Spring1998
Summer1998
Fall1998
Spring1999
Summer1999
Season and Year

CHAPTER III

HABITAT USE BY RACCOONS AND OPOSSUMS AT MULTIPLE SCALES IN THE CROSS TIMBERS ECOREGION OF OKLAHOMA

ABSTRACT

Spatial scale is integral to understanding which habitat components are associated with which species. My objective was to examine selection by opossums (*Didelphis virginiana*) and raccoons (*Procyon lotor*) at microhabitat (trapsite) and macrohabitat (habitat class) levels on a managed cross timbers ecosystem in central Oklahoma. Species were livetrapped within the study area. Habitat variables in the understory and overstory were measured and analyzed versus trap-site success. At trap sites, hardwood leaf litter, distance to water, and average basal area of all trees were associated with opossum capture. Distance to water and average basal area of eastern redcedars (*Junipernus virginiana*) were associated with raccoon captures. Habitat type was classified from an aerial photograph and trapsite locations were overlaid on habitat types using a Geographic Information System (GIS). Habitat classes at capture sites of opossums and raccoons were analyzed using categorical modeling and Bonferroni intervals to detect use of habitat types relative to availability. Opossums used oak forests and bottomland forests during spring and summer more than their availability. Grassland and cedar-associated areas were used less than their availability during the same seasons. Raccoons used all habitats according to availability during all seasons. Microhabitat appeared to be an inappropriate scale for assessing habitat selection of both opossums and raccoons, whereas macrohabitat was appropriate for opossums and raccoons at the Cross Timbers Experimental Range, Payne County, Oklahoma.

INTRODUCTION

The role of spatial scale on ecological processes such as habitat selection has gained increased attention lately (Morris 1987, Oehler and Litvaitis 1996). Morris (1987) and Brown and Litvaitis (1995) stated that species perceive habitats at multiple scales. Selection of specific habitats by a species is a function of landscape composition. For example, at a landscape scale, a species may concentrate along an edge in a homogeneous landscape, thereby leading researchers to conclude edge selection by the species (Oehler and Litvaitis 1996). However, in a fragmented landscape, the same species may not be detected as selecting edge because edge is more abundant than in the homogeneous landscape. At a habitat level, species may appear to prefer one habitat over another based on criteria such as presence of den sites or cover from predation. However, selection may actually be due to specific microhabitat components, such as food or water, found in that particular habitat rather than the habitat itself.

The influence of landscape heterogeneity on mesocarnivores recently has received increased attention. Oehler and Litvaitis (1996) found that in low-diversity landscapes, raccoons responded to edges more than in high-diversity landscapes. Dijak and Thompson (2000) found that raccoon relative abundance was related to riparian areas and stream density. Opossums, according to the findings of Dijak and Thompson (2000), responded to contagion (a measure of landscape heterogeneity), stream density, and mean nearest distance between forest patches at the landscape scale. These authors were unable to find any correlation between relative abundance of mesocarnivores and forest interior or edge at a local scale. Pedlar et al. (1997) investigated raccoon habitat use at different spatial scales. They found that raccoon relative abundance was correlated with sugar maple (*Acer saccharum*), white ash (*Fraxinus americana*), and woody vegetation

1-2 m in height at local scales and with habitat edge and cornfields at a landscape scale. However, Dijak and Thompson (2000) and Pedlar et al. (1997) used scent station plates. Although scent station plates give an index of relative abundance, it is unknown if tracks are from many animals or a single animal many times.

The association of species with habitats and the degree of interspersion of habitats has been discussed for almost 70 years (Leopold 1933). Numerous studies have examined habitat use and occurrence of opossums (*Didelphis americana*) and raccoons (*Procyon lotor*) separately (Fitch and Sandidge 1953, Sanderson 1987, Seidensticker et al. 1987). Fitch and Sandidge (1953) and Seidensticker et al. (1987) reported that opossums used forests and thickets, especially close to water, pastures, and forest edges. Kaufmann (1982) and Sanderson (1987), in reviews, stated that raccoons were common wherever water was found and that they preferred hardwood swamps and other water-associated stands.

Other mesocarnivore research has been devoted to the role of fine-scale variables such as tree size (Leberg and Kennedy 1988, Kennedy et al. 1991) and other microhabitat features (Kissell and Kennedy 1992, Pedlar et al. 1997). Leberg and Kennedy (1988) found that raccoon captures and densities were correlated positively with large deciduous trees and negatively with small-diameter conifers and distance to shoreline with deciduous trees. Kennedy et al. (1991) found a positive association of raccoon capture with diameter at breast height of snags. However, no research has reported on nonwoody microhabitat composition.

Few studies have studied opossums and raccoons concurrently (McKeever 1959, Conner et al. 1983, Kissell and Kennedy 1992, Dijak and Thompson 2000). McKeever

(1959) found that opossums were captured more often in pine-hardwoods, bottomlands, and tall weeds-broomsedge habitats, whereas raccoons had a similar rate of catch per unit effort across all habitats. Kissell and Kennedy (1992) found a higher density of opossums in more heterogeneous habitat versus homogeneous habitat but observed a reverse relationship for raccoons. My objectives were to: 1) investigate habitat use of raccoons and opossums at the microhabitat (trap sites) level; 2) investigate association of raccoons and opossums at a macrohabitat (vegetation type) scale; 3) examine the efficacy of different scales in detecting habitat associations of these species in sympatry.

STUDY AREA

The Cross Timbers Experimental Range (CTER), owned by Oklahoma State University, has been used since 1983 to study vegetation management in the Cross Timbers (Engle et al. 1991, Stritkzc et al 1991), livestock production (McCollum et al. 1987) and wildlife. CTER is located 11 km southwest of Stillwater, Payne County, OK (36°02'40" to 36°04'20"N, 97°09'30" to 97°11'39"W). The overstory is primarily post oak (*Quercus stellata* Wang.), blackjack oak (*Q. marilandica* Muench.), and American elm (*Ulmus americana* L.) interspersed with eastern redcedar. Little bluestem [*Schizachyrium scoparium* (Michx.) Nash.], indiangrass [*Sorgahastum nutans* (L.) Nash.], swithgrass *(Panicum virgatum* L.), grama grasses (*Bouteloua* spp.), purpletop [*Tridens flavus* (L.) Hitchc.], ragweed (*Ambrosia* spp.), and buckbrush (*Symphoricarpos orbiculatus* Moench.) are prevalent in the understory (Ewing et al. 1984).

The land-use history of CTER started as homestead and private cultivation of crops such as cotton (Ewing et al. 1984). In 1983, a regime of herbicide, fire, and combinations of each was prescribed to examine ecosystem response at the scale of 32-ha treatments.

The area now encompasses 712 ha comprising 22, 32.4-ha pastures (Fig. 1). Pastures have undergone different treatment regimes, producing a landscape mosaic of habitat types. The CTER comprise 5 experimental treatments randomly assigned within 4 replicate groups blocked by soil type and original total woody canopy cover. Treatments were tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N`-dimethylurea, Dow Elanco, Indianapolis, Indiana, USA) applied aerially at 2.2 kg/ ha in March 1983; tebuthiuron with prescribed burning; triclopyr ([(3,5,6-trichlor-2-pyridinyl)oxy]acetic acid, Dow Elanco) applied aerially at 2.2 kg/ha in June 1983; and triclopyr with prescribed burning; and control (no herbicide or burning; Table 1). The triclopyr alone treatment was supplemented with prescribed fire starting in 1996 on a 3-year cycle.

Tebuthiuron is a soil-applied herbicide absorbed through root systems. Application at CTER resulted in die-off of most woody species, thereby allowing eastern redcedar to become established. Triclopyr is a foliar-applied herbicide absorbed through the leaf surface that primarily kills broadleaf species including deciduous woody plants. When aerially applied, it allows release of understory woody species if the overstory is sufficiently dense to intercept the herbicide. When either herbicide treatment is combined with a spring headfire regime, remaining woody species are reduced (Engle et al. 1991, Stritzke et al. 1991). Four derived habitat types resulted from treatments applied (D.M. Engle, *personal communication*): eastern redcedar forest, derived grassland, brush-grassland community, and mature oak forest (Tables 1, 2). The 4 habitat types resulting from the treatments were validated by classifying habitat types on an 1998 aerial black and white photograph (scale 1:4,875) with the aid of extensive ground reconnaissance (Table 3).

METHODS

Experimental Design and Sampling

Four of the 5 experimental treatments were sampled. Pastures treated with tebuthiuron only, tebuthiuron-and-fire, triclopyr-with-recent-fire, and control pastures were chosen. Triclopyr-and-fire produced a derived grassland habitat similar to the tebuthiuron-and-burning treatment and was not sampled due to logistical constraints. Edges between treated pastures were sampled as a separate treatment. There were 4 replicates of each treatment except for the tebuthiuron treatment, which lost a replicate to a crown fire that burned most of the pasture in 1996.

Trapping was conducted seasonally in 1998 and 1999, with 4 consecutive 10-day trapping periods (1 period / replicate / season). Seasons were defined as spring (Apr-May), summer (Jul-Aug), and Fall (Sep-Nov). In pasture interiors, trapping grids were set up in a variation of a 3 x 5 grid for a total of 8 traps (Fig. 2, Chapter 1). Traps were located 100-m from the edges of the pasture to diminish edge effects. Traps were located 300-m apart along parallel transects spaced at 200-m intervals, and there was 2 interior plots 180 m diagonally from the corners (Fig. 2, Chapter 1). Edges were trapped along the long axis of the pastures starting 200-m from a pasture corner with traps placed every 200-m. Eight edge traps were used in each 10-day trapping period to equalize representation among pastures. Due to a limited number of traps, edge areas were not trapped during summer 1998. Traps were checked daily.

Animals were sampled using Tomahawk (Tomahawk Trap Company, Tomahawk, Wisconsin, USA) wire-mesh traps (25 x 31 x 81 cm) baited with sardines. Animals were identified by species, anesthetized with Telazol (tiletamine hydrochloride and zolazepam hydrochloride; Fort Dodge Animal Supply, Fort Dodge, Iowa, USA) at 8-mg / kg estimated body mass, ear-tagged with #4 Monel tags (National Band and Tag, Newport, Kentucky, USA), sexed, aged (adult, juvenile), and weighed (kg) with a spring scale (Chatillon Scale Company, New York, New York, USA). Total, tail, hindfoot, ear, and canine lengths were recorded on the left side to the nearest 1.0-mm with a flexible tape. Animal location was recorded as a replicate –treatment code combination and trap-site number. If an animal had been already captured in a 10-day trapping session, it was released following recording of species, ear-tag number, and location. If the animals had been captured before, but not during, the current trapping season, then the animal was handled in the same manner as a new capture.

Microhabitat Variables and Analysis

During summer 1998 and 1999, microhabitat data were collected from each trap location. Percent cover of live grass, live forb, live wood, bareground, rock, woody litter, and other litter was estimated visually within a 1-m^2 frame (Bonham 1989: 128-129). Visual obstruction at a trap point was assessed with a 1-m tall board, with alternating 0.1-m dark and light blocks, placed 4 m from the trap point in 4 directions: northeast (45^o), southeast (135^o), southwest (225^o), and northwest (315^o). Blocks that were completely obstructed were counted. Overhead canopy cover was measured using a sighting tube (Bonham 1989). Data were collected from the trap point and at 4 points, northeast (45^o), southeast (135^o), southwest (225^o), and northwest (315^o), 10 m from the trap point. Data from all 5 locations were averaged to obtain a mean value for that trap point. Within an 8.91-m radius circle (0.025-ha) centered on the trap site, trees >5 cm in diameter at breast height (dbh) were identified to species, dbh (cm) was measured, and tree class recorded (live, standing dead, etc.) and crown class were recorded (dominant, co-dominant, suppressed). Basal area for each tree (m^2) was calculated from dbh as: basal area = 0.00007854 dbh^2 (Young and Giese 1990: 263). Basal area density (m^2/ha) was calculated for each group of tree species (oaks, eastern redcedar, non-oak deciduous, unknown, and summed across groups [total]) at each trap site. Using ArcView 3.2 (Environmental Systems Research Institute, Redlands, California, USA), I calculated distance to nearest habitat edge, water (stream or pond), and fencelines for each trap site from the digitized map of CTER.

I compared understory, overstory, and distance variables for differences between successful and unsuccessful trapsites and for interactions with year (PROC GLM, SAS Institute Inc. 1990). If no year interaction existed, variables were averaged across years. These variables were tested for significance ($\alpha = 0.10$) regarding presence / absence of raccoons and opossums using *t*-tests (PROC TTEST, SAS Institute Inc. 1990). Significant habitat variables were incorporated into a stepwise discriminant analysis model (PROC STEPDISC, SAS Institute Inc. 1990) to select variables that separated between absence and presence at trap sites. Next, discriminant analysis (PROC DISCRIM, SAS Institute Inc. 1990) with jackknifing was used to develop a model that could discriminate between successful and non-successful trap sites. Finally, multiple regression (PROC REG, SAS Institute Inc. 1990) was performed using total number of captures at each site as the dependent variable and significant variables from the stepwise discriminant analysis as independent variables. Alpha level was set at 0.05 for these analyses.

Macrohabitat Variables and Analysis

Using a 1998 aerial black and white photograph of the study area and extensive ground reconnaissance, I delineated and digitized habitat types. Ten habitats were delineated (Table 2, Fig. 1) based upon vegetation composition. Fence corners and irregularities were georeferenced using a hand-held Global Positioning System (GPS; Trimble Navigation Systems) and then overlaid on the habitat map using Shapewarp 2.2 in ArcView 3.2 (ESRI). Individual trap sites were georeferenced using GPS and overlaid on the habitat coverage to obtain habitat classification for each site. Frequency of captures in each habitat type was compared with habitat availability (number of traps in each habitat class) using log-linear analysis (PROC CATMOD / CHISQ, SAS Institute Inc. 1990) for use-availability differentiation. I assumed that 1) attractiveness of baited traps was independent of habitat type and 2) the probability of being trapped in a particular type was proportional to use of that habitat for foraging and movements. Seasons were pooled across years due to low capture numbers within individual trapping sessions. When overall significance was obtained, Bonferroni confidence intervals were calculated following Neu et al. (1974) and Byers et al. (1984) to determine which habitats were used more or less than their availability.

RESULTS

Microhabitat

No interaction was found between year and trapsites (successful vs. unsuccessful) for any of the microhabitat variables measured. Distance to water was lower for successful trapsites than unsuccessful trapsites (Table 4). Several measures of woody structure and composition also differed among successful and unsuccessful trapsites (Table 4). Basal area and stem densities were typically greater at successful trapsites.

Significant microhabitat variables were entered into stepwise discriminant analysis. The resulting model for opossums selected oak average basal area, total average basal area, distance to water, and percent hardwood leaf litter as discriminating between successful and unsuccessful trap sites. Discriminant analysis with jackknifing was used to examine predictive ability of those variables. The opossum model accurately classified successful trap sites 62.5% of the time, whereas unsuccessful trap sites were classified 91.7% of the time. The reduced multiple regression model for opossum occurrence at a trap site was opossum captures = 1.72 + 0.04(hardwood leaf litter) – 0.003(distance to water) + 873.5(average total basal area). This model was significant (F = 14.61, $P < 0.001$) but explained only 31.4% of the variation in capture frequencies at individual trapsites. Cover of hardwood leaf litter was the best predictor ($P < 0.001$), whereas distance to water ($P = 0.07$) explained a minimal amount of variation. Average oak basal area and total average basal area were not significant in the multiple regression ($P = 0.21$ and $P = 0.26$, respectively).

Water was closer to successful trap sites than to unsuccessful trap-sites of raccoons. Average basal area of oaks and non-oaks were higher at successful trap-sites. Cedar basal area and average basal area of cedar were lower at successful trap sites (Table 5). No other microhabitat variables varied by trap site type.

The stepwise discriminant model selected distance to water and average basal area of cedars as providing discrimination between successful and unsuccessful trap sites. The raccoon model correctly classified successful trap sites 86.1% of the time, whereas unsuccessful trap sites were classified only 36.6% of the time. The resulting multiple regression model was raccoon captures = 1.94 – 0.003(distance to water) – 0.48(average basal area of cedars). This model was significant ($F = 5.55$, $P = 0.005$), but only explained 7.1% of the variation in capture frequencies at individual trap sites. Distance to water was stronger ($P = 0.014$) than average basal area of cedars ($P = 0.05$) in explaining variation in raccoon capture frequencies at individual trap sites.

Macrohabitat

Opossums were trapped in habitats differing to their availability during spring ($\chi^2_8 = 22.1$, $P = 0.005$) and summer ($\chi^2_8 = 23.4$, $P = 0.003$). Habitats were used in fall in proportion to availability ($\chi^2_8 = 11.9$, $P = 0.156$). During spring, oak forest and bottomland areas were selected, whereas cedar forest, grasslands, both combinations of cedar and grassland, and scrub-shrub areas were used less than their availability (Table 6). In summer, habitat selection was similar to spring except cedar forest and scrub-shrub were used according to availability, whereas cedar-scrub was selected against (Table 6). Raccoons used all habitats in accordance with availability during all seasons ($P > 0.173$; Table 7).

DISCUSSION

Microhabitat

My results were consistent with previous literature showing that opossums favor deciduous habitats (Seidensticker et al. 1987, Gardner 1982). Percent hardwood leaf litter may have served as a surrogate for several variables of woody cover in discriminating successful trap sites for opossums. The association of opossums with deciduous habitats may be due to added cover and protection from predation, daytime resting sites, and increased availability of forage such as acorns.

Water is associated strongly with opossum occurrence (Seidensticker et al. 1987, Gardner 1982). This association is due to increased foraging opportunities along the fertile soils associated with bottomlands and ponds. Successful trap sites for opossums were closer to water than unsuccessful trapsites, agreeing with previous research (Kissell and Kennedy 1992).

Few microhabitat variables were associated with raccoon captures at CTER, in contrast to previous work. Leberg and Kennedy (1988) found deciduous basal area >50-cm and basal area of snags to be correlated positively with raccoon density, whereas basal area of conifers (10 to 20-cm) was correlated negatively with raccoon density. Similarly, Kennedy et al. (1991) reported snags with diameter breast height of 20 to 50 cm to be correlated positively with raccoons. Kissell and Kennedy (1992) found small- and large-diameter hardwoods to be associated positively with raccoons; however, they used Bonferroni corrections and concluded that these associations were not statistically significant.

My findings indicated only a negative association of raccoons with average cedar basal area, in agreement with the findings of Kennedy et al. (1991) and Leberg and Kennedy (1988) for other coniferous species. This negative association may be a result of the sparse understory, and therefore little forage, often associated with conifers (Pedlar et al. 1997).

Differences in landscape heterogeneity will influence selection of habitat by a species (Oehler and Litvaitis 1996, Morris 1987). For example, the habitat composition was markedly different between the studies of Kennedy et al. (1991) and Leberg and Kennedy (1988) and my study. CTER is highly fragmented with small patches of habitat, whereas the studies of Kennedy et al. (1991) and Leberg and Kennedy (1988) were conducted in more homogeneous landscapes. Therefore, the ranging behavior of raccoons at CTER would allow them to cross many different habitats, increasing captures at trapsites as they moved through rather than as they were foraging.

The association of raccoon captures to proximity to water has been reported elsewhere (Leberg and Kennedy 1988, Kissell and Kennedy 1992). Kaufmann (1982) and Sanderson (1987) reported strong associations of raccoons with water. Similar to opossums, this association may result from increased foraging opportunities found along streams and ponds.

Macrohabitat

Macrohabitat selection by opossums was similar to observations in the literature. Allen et al. (1985), Seidensticker et al. (1987), and Wilson (1996) found that opossums were prevalent in bottomland areas and along small or intermittent streams. Similarily, Gardner (1982) stated opossum preferred deciduous woodlands with stream associations. During spring and summer at CTER, opossum habitat use showed selection for oak forest and bottomland habitats. This may be due to increased forage potential in these areas because of highly fertile soils (Dijak and Thompson 2000). Fitch and Sandidge (1953) reported concentration of opossum activity in woodland areas. During spring, acorns in oak forests compose an important early food source (Wood 1954). Oak forests also provide daytime resting sites (Gardner 1982, Seidensticker et al. 1987). My findings at CTER also are in general agreement with the literature regarding opossum selection against grasslands (Llewellyn and Dale 1964, Gardner 1982, Allen et al. 1985, Llewellyn and Dale 1964 Wilson 1996) and coniferous areas (Wilson 1996). Increased movements in fall due to dispersal may have increased captures in a range of habitats, muting habitat selection in fall.

Raccoons are reported in hardwood areas associated with water (Sanderson 1987, Kaufmann 1982). Grass pastures and pine-associated areas have been reported to be avoided (Sanderson 1987, Kaufmann 1982); however, Wilson (1996) found raccoon selected mixed pine – hardwood forests greater than available. I did not detect any selection of habitats at CTER for raccoons. However, due to the small patch size on CTER ($n = 440$; $\bar{x} \pm SD = 5.06 \pm 0.18$ ha) and the large home-range size and movement distances (Kaufmann 1982, Fritzell 1978), raccoons may have an increased chance of capture at random trapsites.

The role of spatial scale in understanding ecological processes is critical for proper management of landscapes (Morris 1987). At CTER, it appears that microhabitat scale is an inappropriate scale for assessing habitat selection of both opossums and raccoons. The habitat scale appears appropriate for opossums but not for raccoons at CTER. This may be attributed to the size and fragmented nature of CTER relative to the ranging behavior and movement ability of opossums and raccoons. It is important that both microhabitat and macrohabitat variables measured be non-trivial (Pedlar et al. 1997). All variables I used were potential indicators of opossum and raccoon occurrence based upon the literature.

Pedlar et al. (1997) reported that their microhabitat, macrohabitat, and combined models explained 25-30% of the variation in raccoon selection. My opossum model explained 27%, whereas the raccoon model explained only 5% of the total variation. Both Pedlar et al. (1997) and CTER selection models are unsuitable measures of indicators of species occurrence. However, models such as Pedlar et al. (1997) and mine are derived from indices of raccoon and opossum selection, which may be measures of movement through an area rather than actual selection of that area. Further research involving a more direct measure of animal selection (e.g., telemetry) may give a better understanding to the role and appropriateness of spatial scale to habitat selection of mesocarnivores.

Opossums and raccoons may have operated at different scales on CTER based upon their ranging and movement patterns. This scale difference may allow for co-existence in a fragmented landscape characteristic of CTER. Body mass differences (opossum: $\bar{x} \pm$ SE = 1.9 ± 0.1 kg , raccoon: 4.9 ± 0.2 kg) also may contribute to resource partitioning. Studies of other mesocarnivore guilds have documented resource partitioning by body size (Fedriani et al. 2000, Jones and Barmuta 2000).

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Table III.1. Timing of treatment regime at Cross Timbers Experimental Range, Payne County with resulting habitat types (D. M. Engle *personal communication*).

	Treatment regime			
Treatment	Herbicide	Burn	Mechanical	Current Habitat[a]
1	Tebuthiuron 1983	None	None	Cedar forest
2	Tebuthiuron 1983; P+D[b] 1997	1985, 86, 87, 90, 93, 96, 99	None	Derived grassland
3	Triclopyr 1983; 2,4-D 1988; P+D[b] 1994, 1997	1993, 96, 99	Bulldoze and windrow redcedar pre- 1996; Saw cedar post-1996	Scrub- shrub forest
5	None	None	None	Mature oak forest

[a] D. M. Engle, *personnel communication*

[b] picloram + 2,4-D

Table III.2: Average area (ha; $\bar{x} \pm$ SE) and % habitat in each treatment (n = 4 replicates / treatment) on the Cross Timbers Experimental Range, Payne County, Oklahoma.

Habitat Type	Tebuthiuron only		Tebuthiuron-and-fire		Triclopyr-and-fire		Control	
	Area	%	Area	%	Area	%	Area	%
Grassland	7.2 ± 3.4	20.8 ± 9.8	14.5 ± 1.6	43.5 ± 4.8	9.1 ± 2.1	27.2 ± 6.3	3.4 ± 0.6	10.2 ± 1.8
Oak forest	1.6 ± 1.4	4.6 ± 4.0	1.8 ± 1.1	5.4 ± 3.3	1.7 ± 1.1	5.1 ± 3.3	18.3 ± 2.2	55.0 ± 6.6
Cedar forest	14.4 ± 3.1	41.6 ± 9.0	0.8 ± 0.3	2.4 ± 0.9	3.8 ± 1.3	11.4 ± 3.9	1.7 ± 1.1	5.1 ± 3.3
Grassland-Cedar	3.7 ± 2.9	10.7 ± 8.4	6.0 ± 1.4	18.0 ± 4.2	0.5 ± 0.0	1.5 ± 0.0	1.5 ± 1.4	4.5 ± 4.2
Cedar-Grassland	2.5 ± 0.9	7.2 ± 2.6	4.7 ± 0.8	14.1 ± 2.4	0.4 ± 0.2	1.2 ± 0.6	4.4 ± 1.6	13.2 ± 4.8
Scrub-shrub forest	1.9 ± 1.6	5.5 ± 4.6	2.0 ± 0.2	6.0 ± 0.6	13.1 ± 1.8	39.2 ± 5.4	0.3 ± 0.2	0.9 ± 0.6
Bottomland	0.8 ± 0.4	2.5 ± 1.2	1.2 ± 0.2	3.6 ± 0.6	0.7 ± 0.1	2.1 ± 0.3	0.9 ± 0.1	2.7 ± 0.3
Cedar-Oak forest	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.9	2.7 ± 2.7	1.0 ± 0.3	3.0 ± 0.9	0.6 ± 0.5	1.8 ± 1.5
Cedar-Scrub	2.5 ± 0.4	7.2 ± 1.2	1.2 ± 0.2	3.6 ± 0.6	2.9 ± 0.3	8.7 ± 0.9	2.2 ± 0.0	6.6 ± 0.0
Pond	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.0	0.6 ± 0.0	0.2 ± 0.1	1.2 ± 0.3	0.0 ± 0.0	0.0 ± 0.0

Table III.3: Criteria for habitat delineation on the Cross Timbers Experimental Range, Payne County, Oklahoma.

Habitat Classification	% Cover Grassland	% Cover Oak Forest	% Cover Redcedar Forest	% Cover Non-Oak Forest
Grassland	>75.0	<10.0	<10.0	<10.0
Grassland-Cedar	>50.0	<10.0	<50.0	<10.0
Cedar-Grassland	<50.0	<10.0	>50.0	<10.0
Cedar forest	<10.0	<10.0	>75.0	<10.0
Oak forest	<10.0	>75.0	<10.0	<10.0
Non-oak forest[1]	<10.0	<10.0	<10.0	>75.0
Cedar-Oak forest	<10.0	25.0-75.0	25.0-75.0	<10.0
Cedar-Non-oak[2]	<10.0	<10.0	25.0-75.0	25.0-75.0

[1] Includes bottomland and scrub-shrub forest.
[2] Includes cedar-scrub forest.

Table III.4. Microhabitat variables at unsuccessful (n = 24) and successful (n = 96) trapsites for opossums on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

	Unsuccessful		Successful				
Variable	$\bar{x}$	SE	$\bar{x}$	SE	t	df	$P > \|t\|$
Forb cover (%)	10.24	1.92	10.16	0.90	0.04	118.0	0.968
Grass cover (%)	49.50	4.63	29.83	2.47	3.49	118.0	0.001
Woody cover (%)	9.22	1.91	12.81	1.14	1.39	118.0	0.166
Bareground (%)	15.21	2.00	14.05	1.17	0.44	118.0	0.663
Rock (%)	1.01	0.39	1.15	0.37	0.17	118.0	0.863
Leaf litter (%)	2.57	0.84	21.74	2.59	7.03	112.6	0.000
Other litter (%)	33.54	4.26	32.56	2.14	0.20	118.0	0.843
Overhead density (%)	26.00	5.33	48.67	3.11	3.22	118.0	0.002
Visual obstruction (%)	33.80	3.90	29.50	1.70	1.04	118.0	0.301
Coarse woody debris (%)	5.64	1.03	4.24	0.34	1.28	25.7	0.212
Stems <5.0 cm (stems / ha)	522.50	133.75	625.00	82.50	0.55	118.0	0.585
Distance to edge (m)	30.93	7.87	20.51	2.45	1.26	25.2	0.218
Distance to water (m)	183.16	28.62	109.43	9.81	2.44	26.1	0.022
Distance to fence (m)	122.93	10.13	115.83	4.52	0.67	118.0	0.507
Oak basal area (m^2 /ha)	0.07	0.051	2.15	0.42	4.87	97.6	0.0001
Oak stems (stems / ha)	0.13	0.07	2.41	0.48	4.69	98.8	0.0001
$\bar{x}$ Oak basal area (m^2 /ha / stem)	0.07	0.05	0.45	0.08	8.86	113.9	0.0002

Table III.4 continued

Cedar basal area (m^2 /ha)	1.29	0.31	1.73	0.20	1.01	118.0	0.314
Cedar stems (stems / ha)	3.04	0.71	3.49	0.33	0.59	118.0	0.556
$\bar{x}$ Cedar basal area (m^2 /ha / stem)	0.44	0.11	0.45	0.05	0.12	118.0	0.903
Non-oak basal area (m^2 /ha)	0.23	0.11	0.65	0.19	1.96	115.5	0.053
Non-oak stems (stems / ha)	0.63	0.29	1.44	0.37	1.09	94.6	0.087
$\bar{x}$ Non-oak basal area (m^2 /ha / stem)	0.13	0.07	0.19	0.05	0.62	118.0	0.533
Total basal area (m^2 /ha)	1.59	0.35	4.53	0.44	5.17	95.3	0.0001
Total stems (stems / ha)	3.83	0.70	7.34	0.62	3.76	63.3	0.0004
$\bar{x}$ Total basal area (m^2 /ha / stem)	0.33	0.06	0.66	0.06	4.06	76.4	0.0001

Table III.5. Microhabitat variables at unsuccessful ($n = 41$) and successful ($n = 79$) trapsites for raccoons on Cross Timbers Experimental Range, Payne County, Oklahoma, 1998-1999.

	Unsuccessful		Successful				
Variable	$\bar{x}$	SE	$\bar{x}$	SE	t	df	$P > \|t\|$
Forb cover (%)	9.34	1.22	10.59	1.06	0.72	118.0	0.472
Grass cover (%)	37.37	3.93	31.46	2.81	1.22	118.0	0.225
Woody cover (%)	12.56	1.71	11.95	1.24	0.29	118.0	0.775
Bareground (%)	12.27	1.46	15.27	1.34	1.51	98.4	0.134
Rock (%)	1.79	0.74	0.79	0.28	1.26	50.9	0.212
Leaf litter (%)	14.46	3.66	20.10	2.79	1.20	118.0	0.234
Other litter (%)	34.49	3.94	31.86	2.09	0.59	61.6	0.558
Overhead density (%)	42.67	4.78	45.33	3.56	0.45	118.0	0.650
Visual obstruction (%)	30.70	2.90	30.10	1.90	0.19	118.0	0.853
Coarse woody debris (%)	5.15	0.64	4.18	0.39	1.37	118.0	0.173
Stems <5.0 cm (stems / ha)	563.75	107.50	627.50	93.75	0.41	118.0	0.681
Distance to edge (m)	25.72	5.47	20.77	2.52	0.82	56.1	0.414
Distance to water (m)	159.70	19.07	104.57	10.85	2.70	118.0	0.008
Distance to fence (m)	111.05	6.95	120.17	5.11	1.04	118.0	0.299
Oak basal area (m^2 /ha)	1.27	0.52	1.98	0.45	0.97	118.0	0.335
Oak stems (stems / ha)	1.61	0.64	2.13	0.50	0.62	118.0	0.536
$\bar{x}$ Oak basal area (m^2 /ha / stem)	0.21	0.07	0.45	0.10	1.97	117.6	0.051

Table III.5 continued

Cedar basal area (m^2 /ha)	2.06	0.32	1.42	0.20	1.79	118.0	0.076
Cedar stems (stems / ha)	3.39	0.50	3.41	0.38	0.02	118.0	0.982
$\bar{x}$ Cedar basal area (m^2 /ha / stem)	0.65	0.11	0.34	0.04	2.77	50.6	0.008
Non-oak basal area (m^2 /ha)	0.32	0.12	0.69	0.22	1.49	112.0	0.139
Non-oak stems (stems / ha)	1.05	0.36	1.39	0.42	0.63	114.2	0.532
$\bar{x}$ Non-oak basal area (m^2 /ha / stem)	0.10	0.04	0.22	0.06	1.73	117.9	0.087
Total basal area (m^2 /ha)	3.65	0.62	4.09	0.48	0.55	118.0	0.583
Total stems (stems / ha)	6.05	0.87	6.95	0.66	0.81	118.0	0.421
$\bar{x}$ Total basal area (m^2 /ha / stem)	0.61	0.09	0.59	0.06	0.18	118.0	0.861

Table III.6. Use and availability of habitats for opossums based on trapping across seasons on Cross Timbers Experimental Range, Payne County, Oklahoma 1998-1999.

Habitat	Season	Proportion Available	Proportion Used	Bonferroni Interval	Selection
Grassland	Spring	0.2368	0.1513	0.1349 – 0.1677	Avoided[b]
	Summer	0.1949	0.1364	0.1181 – 0.1547	Avoided
	Fall	0.2368	0.2350	[a]	
Oak Forest	Spring	0.1382	0.2857	0.2650 – 0.3064	Preferred[c]
	Summer	0.1471	0.3295	0.3044 – 0.3546	Preferred
	Fall	0.1382	0.2200	[a]	
Cedar Forest	Spring	0.1250	0.0924	0.0791 – 0.1057	Avoided
	Summer	0.1360	0.1250	0.1074 – 0.1426	None[d]
	Fall	0.1250	0.1050	[a]	
Scrub-Shrub	Spring	0.1447	0.1092	0.0949 – 0.1235	Avoided
	Summer	0.1397	0.1591	0.1396 – 0.1786	None
	Fall	0.1447	0.1400	[a]	
Bottomland	Spring	0.0658	0.1429	0.1269 – 0.1589	Preferred
	Summer	0.0698	0.1023	0.0861 – 0.1185	Preferred
	Fall	0.0658	0.1050	[a]	

Table III.6 continued

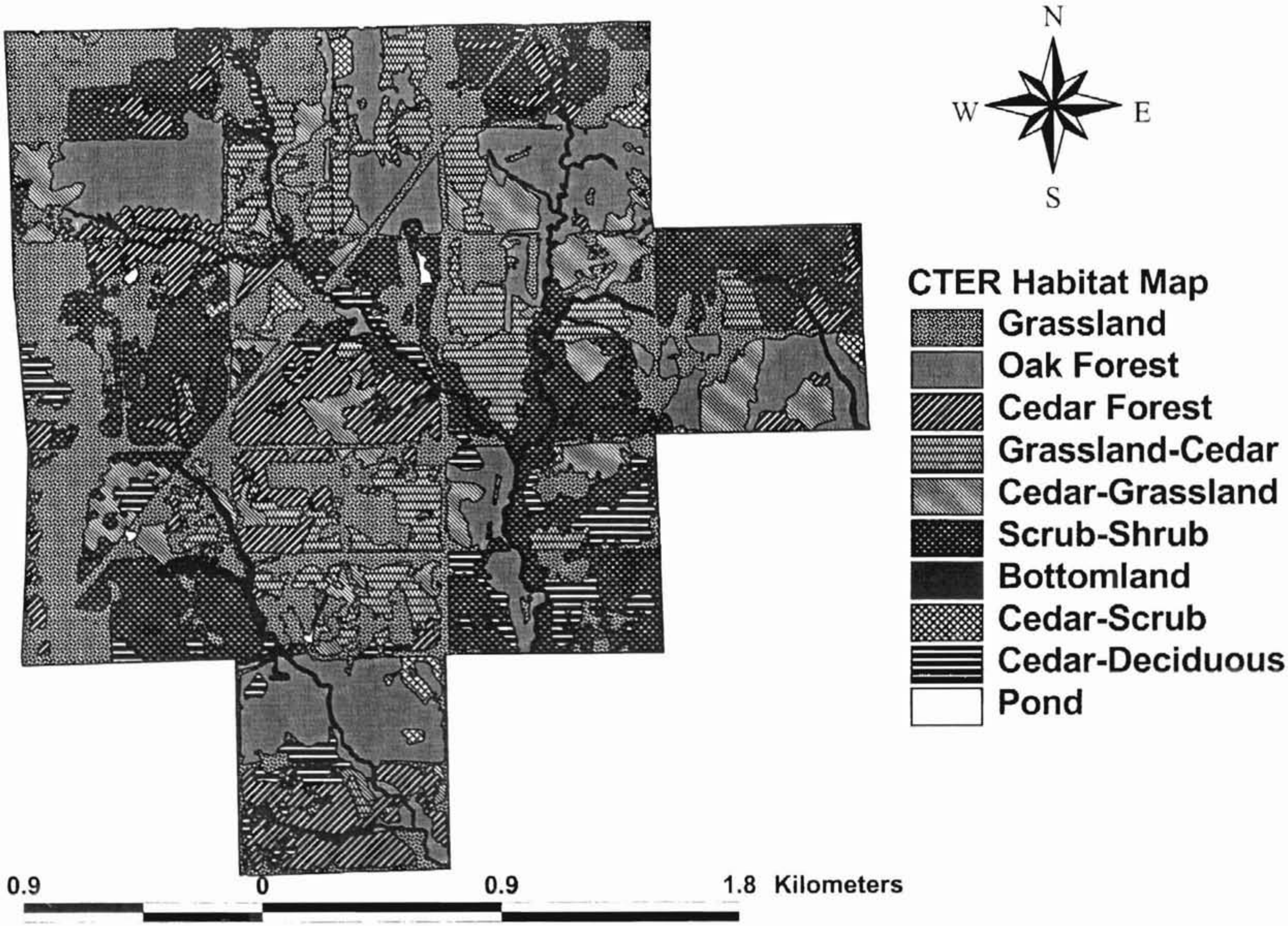
Grassland – Cedar	Spring	0.0855	0.0504	0.0404 – 0.0604	Avoided
	Summer	0.0882	0.0114	0.0570 – 0.0171	Avoided
	Fall	0.0855	0.0550	[a]	
Cedar – Grassland	Spring	0.1184	0.0840	0.0713 – 0.0967	Avoided
	Summer	0.1324	0.0795	0.0651 – 0.0939	Avoided
	Fall	0.1184	0.0850	[a]	
Cedar – Oak Forest	Spring	0.0263	0.0252	0.0180 – 0.0324	None
	Summer	0.0294	0.0227	0.0180 – 0.0324	None
	Fall	0.0263	0.0200	[a]	
Cedar – Scrub	Spring	0.0592	0.0588	0.0480 – 0.0696	None
	Summer	0.0625	0.0341	0.0244 – 0.0438	None
	Fall	0.0592	0.0350	[a]	

[a] Bonferroni Intervals were not calculated due to non-significance in Chi-square analysis.
[b] Used less than availability.
[c] Used greater than availability.
[d] Use not different from availability.

Table III.7. Use and availability of habitats for raccoons based on trapping across seasons on Cross Timbers Experimental Range, Payne County, Oklahoma 1998-1999.

Habitat	Season	Proportion Available	Proportion Used
Grassland	Spring	0.2368	0.2027
	Summer	0.1949	0.1071
	Fall	0.2368	0.2121
Oak Forest	Spring	0.1382	0.2162
	Summer	0.1471	0.1786
	Fall	0.1382	0.1970
Cedar Forest	Spring	0.1250	0.2027
	Summer	0.1360	0.1449
	Fall	0.1250	0.1667
Scrub-Shrub	Spring	0.1447	0.0541
	Summer	0.1397	0.0893
	Fall	0.1447	0.1818
Bottomland	Spring	0.0658	0.0405
	Summer	0.0698	0.0893
	Fall	0.0658	0.0758
Grassland – Cedar	Spring	0.0855	0.0676
	Summer	0.0882	0.0536
	Fall	0.0855	0.0303
Cedar – Grassland	Spring	0.1184	0.0946
	Summer	0.1324	0.1964
	Fall	0.1184	0.0601
Cedar – Oak Forest	Spring	0.0263	0.0405
	Summer	0.0294	0.0357
	Fall	0.0263	0.0152
Cedar – Scrub	Spring	0.0592	0.0812
	Summer	0.0625	0.1071
	Fall	0.0592	0.0601

Figure III.1: Habitat layout on the Cross Timbers Experimental Range, Payne County, Oklahoma.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CTER Habitat Map
Grassland
Oak Forest
Cedar Forest
Grassland-Cedar
Cedar-Grassland
Scrub-Shrub
Bottomland
Cedar-Scrub
Cedar-Deciduous
Pond
0.9
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VITA γ

Laurence Paul Levesque

Candidate for the Degree of

Master of Science

Thesis: EFFECT OF LAND-USE MANIPULATIONS ON HABITAT ASSOCIATIONS AND DEMOGRAPHY OF MESOCARNIVORES IN THE CROSS TIMBERS ECOREGION OF OKLAHOMA.

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