

An Abstract of the Thesis of

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Title: Factors affecting habitat use by the fox squirrel (*Sciurus niger rufiventer*) in
fragmented habitat of eastern Kansas

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I conducted a landscape level investigation of habitat use by the fox squirrel (*Sciurus niger rufiventer*) in the predominantly agricultural/grassland matrix of eastern Kansas by combining field data with GIS techniques. I searched for leaf nests on two 15.5 km² study sites containing 130 habitat patches (fragmented woodlots) ranging in size from 0.01-12.9 ha. I measured 12 explanatory variables (five isolation variables, two connectivity variables, and five habitat variables) to generate predictive models of habitat use of fox squirrel. I also applied my data to the existing Habitat Suitability Index (HSI) model for fox squirrel to determine if this model predicted fox squirrel habitat use better than my predictive models. Area ($F_{1,129} = 416.5$, $R^2 = 0.7649$, $P < 0.0001$, $s^2 = 7.53$) was selected as the most important indicator of both leaf nest abundance and the presence/absence of leaf nests by using multiple regression and discriminant function analysis. The HSI model was not an accurate predictor of patches occupied by leaf nests. Modifications to the HSI such as adding an Osage orange (*Maclura pomifera*) variable to the winter food component could make the model more representative of fox squirrel habitat in eastern Kansas.

**Factors affecting habitat use by the fox squirrel (*Sciurus niger rufiventer*) in
fragmented habitat of eastern Kansas**

A Thesis

Presented to

The Department of Biological Sciences

EMPORIA STATE UNIVERSITY

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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To assist me with two attempts at thesis projects prior to this study, funding for three undergraduate field assistants, 50 1.2m long iron stakes, 200 30.5cm x 6cm rebar stakes, 2 tons of sand, a particle sieve, an Ohaus digital scale, film, and use of a vehicle was provided by RNHR. A truck full of acorns and a vehicle was provided by KDWP. D. Ganey and M. Combes offered much advice on study design. R. Ferguson offered much appreciated technical assistance. D. Moore provided the use of his table saw, and L. Robbins donated 125 plastic cafeteria trays. Volunteer field assistance was provided by M. Combes and D. Robinson. Access to study sites was granted by G. Combes, J. Minerath, Emporia State University (Reading and Howe Woods), and J. Gamble at the Flint Hills National Wildlife Refuge.

Preface

In seeking my Master's degree, three and a half years have passed and two "failed" thesis project attempts document the transition of my academic growth. I first proposed to apply foraging theory to an investigation of the potential competition for acorn crop production among white-tailed deer (*Odocoileus virginianus*), fox squirrel (*Sciurus niger*), and white-footed mice (*Peromyscus leucopus*). Naïve and optimistic, I shrugged-off my committee's warnings of "relying on free-ranging deer to feed from elevated food trays is a risky undertaking". Before I could prove otherwise, the third "100-year flood" in a decade wiped out two of my five study sites and the remaining three study sites had hard mast crop failure.

Having first-hand experience with the uncertainty of conducting ecological research in natural systems, and stubbornly sticking with foraging behavior research, I tried a more simplified experimental design by proposing a single species approach in what I assumed would be a more reliable (resource rich) and experimentally manageable environment: "Foraging activities of fox squirrels in agricultural fields of eastern Kansas". How quickly I learned that farming practices are dictated by unpredictable weather patterns. Such study locations do not lend themselves well to experimental "control" or "replication". Perhaps more importantly, I failed to consider the destruction a flock of American crows (*Corvus brachyrhychos*) might have on concentrated piles of seeds mixed in sand. Data were indecipherable and unsalvageable at the scale of that investigation.

My third and final attempt, herein, is an accumulation of my trials, observations, and understanding of fox squirrel ecology; a landscape-level investigation of habitat use

by fox squirrel in agriculturally induced fragmented habitats, using ArcView to analyze and visualize spatial components within the landscape. My thesis is written in the manuscript style of *Landscape Ecology*.

Table of Contents

	<u>Page</u>
Acknowledgments	iii
Preface	v
Table of Contents	vii
List of Tables	viii
List of Figures	ix
List of Appendices	xi
Introduction	1
Methods	6
Results	20
Discussion	39
References	51
Appendix I	59
Appendix II	60

List of Tables

	<u>Page</u>
<i>Table 1.</i> Land uses of Troublesome and Lebo sites.....	23
<i>Table 2.</i> Preference of tree species for leaf nest construction by fox squirrels. Data were pooled for all four areas (Troublesome core area, Troublesome patches, Lebo core area, and Lebo patches). Trees were only identified to genus because leaves were absent at time of identification.....	29
<i>Table 3.</i> Results of discriminant function analysis for predicting presence and absence of leaf nests. Area, # Connections, DBH, and % Canopy cover were selected as the best predictor variables. Lebo site data were modeled and applied to Troublesome site data.....	33

List of Figures

	<u>Page</u>
<i>Figure 1.</i> Location of study area in eastern Kansas.....	8
<i>Figure 2.</i> Location of the two 15.5 km ² sites, Troublesome and Lebo creeks, in Coffey County, Kansas.....	10
<i>Figure 3.</i> Land use map of Troublesome site.....	14
<i>Figure 4.</i> Land use map of Lebo site.....	16
<i>Figure 5.</i> Results of patch type available versus used for Troublesome (A) and Lebo (B) sites.....	22
<i>Figure 6.</i> Girth of trees (DBH) used by fox squirrels for constructing leaf nests in core areas on Troublesome (A) and Lebo (B) sites.....	25
<i>Figure 7.</i> Girth of trees (DBH) used by fox squirrels for constructing leaf nests in patches of Troublesome (A) and Lebo (B) sites.....	27
<i>Figure 8.</i> Results of multiple regression analysis for predicting leaf nests abundance. Area ($F_{1,129} = 416.5$, $R^2 = 0.7649$, $P \geq 0.0001$, $s^2 = 7.53$) was selected as the best one-variable predictive model.....	31
<i>Figure 9.</i> Results of combining data from both sites and applying them to the Winter Food life requisite component of the Habitat Suitability Index (HSI) model (Allen 1982). The model was scaled to produce index values between 0.0 (unsuitable habitat) and 1.0 (optimal habitat) and plotted against number of leaf nests occupying each patch. Those patches occupied by more than 10 leaf nests are indicated as being equal to 10 to allow for the best fit of	

the graph. Symbols represent number of leaf nests (● = 1, ■ = 2, ▲ = 3, Δ = 6, □ = 17, ○ = 84)..... 35

Figure 10. Results of combining data from both sites and applying them to the Cover/Reproduction life requisite component of the Habitat Suitability Index (HSI) model (Allen 1982). The model was scaled to produce index values between 0.0 (unsuitable habitat) and 1.0 (optimal habitat) and plotted against number of leaf nests occupying each patch. Those patches occupied more than 10 leaf nests are indicated as being equal to 10 to allow for the best fit of the graph. Symbols represent number of leaf nests (● = 1, ■ = 2, ▲ = 3, — = 5, Δ = 6, □ = 8, ○ = >8)..... 37

List of Appendices

	<u>Page</u>
<p><i>Appendix I.</i> A SAS program generated by converting Allen’s (1982) Habitat Suitability Index (HSI) model to mathematical equations to simplify the procedure of generating an HSI value for each habitat patch.....</p>	59
<p><i>Appendix II.</i> Summary of nest data, 15 explanatory variables (12 of the variables were used to generate predictive models), and HSI values for 58 and 72 habitat patches on Troublesome and Lebo creeks, respectively. Explanatory variables include: habitat patch type (Patch Type); area; perimeter; distance from each patch to core (DistCore), to nearest water source (DistWater), to nearest grain (DistGrain), to nearest patch, if any, serving as a stepstone to core (DistStepstone), and to nearest occupied patch (DistOccupied); Grain Type; # of corridors; # continuous connections to core (# Connections); % Shrub/Grass cover (% Shrub/Grass); % Canopy closure (% Canopy); and Tree community similarity (TreeCommunity). Available grain types include: alfalfa (a), corn (c), fallow (f), milo (m), soybeans (s), wheat-fallow (w-f), and feedlot (fl). Habitat types include: homestead (hs), hedgerow (hr), fencerow (fr), and woodlot (w).....</p>	60

Introduction

The fox squirrel (*Sciurus niger*) is the largest scansorial squirrel in the Western Hemisphere. The fox squirrel ranges throughout the eastern United States, except for the Northeast, and occurs as far west as the prairie states of North Dakota, Nebraska, Kansas, Oklahoma, and Texas, as well as the northeastern tip of Mexico. Of the ten recognized subspecies, *S. n. rufiventer*, is the most abundant and widespread, occupying all midwestern states west of the Appalachian Mountains and north of Texas, (Koprowski 1991; Whitaker and Hamilton 1998). Increased tree populations in riparian zones, due to suppression of prairie burning since European settlement, have allowed the fox squirrel to expand its range (Koprowski 1991). Human introduction into suburban communities of Washington, Oregon, California, Idaho, South Dakota, Colorado, and Ontario has further distributed the fox squirrel across North America (Flyger and Lustig 1976; Wright 1979).

Despite the stability of *S. n. rufiventer* populations, conservationists and multiple-use resource managers are beginning to express concern for declines in other fox squirrel subspecies populations throughout the eastern United States. Identifying optimal habitat characteristics and predicting patterns of habitat use will be critical for reestablishing the eastern fox squirrel (*S. n. vulpinus*) to its former range in the northeastern states (Flyger and Lustig 1976), for conservation of the endangered Delmarva fox squirrel (*S. n. cinereus*) in Maryland (Talyor 1973), for conservation of *S. n. niger* in the southeastern coastal plain (Weigl et al. 1992), and for translocations of the state threatened Big Cypress fox squirrel (*S. n. avicennia*) in Florida (Jodice 1993). Information about habitat use by *S. n. rufiventer* potentially could be applied to these

conservation issues because of the ecological similarities among subspecies.

Current understanding of fox squirrel ecology is based primarily on studies of *S. n. rufiventer*. The majority of scientific research on fox squirrel food preferences (Baumgras 1944; Bugbee and Riegel 1945; Ofcarcik et al. 1973; Havera and Smith 1979; Korschgen 1981), foraging behavior (Cahalane 1942; Stapanian and Smith 1978; Brown and Batzli 1984; Koprowski 1991; Steele and Weigl 1992; Morgan et al. 1997), population dynamics (Allen 1942; Brown and Yeager 1945; Packard 1956; Nixon and McClain 1969; Hansen et al. 1986; Havera and Nixon 1980; Nixon et al. 1984; Nixon et al. 1985), and management (Nixon et al. 1974; Nixon et al. 1975; Nixon and Hansen 1987) has been conducted on this widespread subspecies.

Distribution of the fox squirrel is influenced greatly by habitat as it relates to food availability (Whitaker and Hamilton 1998). The fox squirrel's response to mast crops is well documented (Barber 1954; Packard 1956; Goodrum et al. 1971; Nixon et al. 1975; Havera and Nixon 1980; Korschgen 1981), although Korschgen (1981) found that mast constituted only half of the fox squirrel diet, while corn (*Zea mays*), Osage orange (*Maclura pomifera*), elm (*Ulmus* spp.), and wheat (*Triticum aestivum*) were equally important seasonal foods in Missouri. Havera and Nixon (1980) reported fox squirrels foraging on soybean (*Lathyrus odoratus*) plants along forest edge in late winter. The fruits, seeds, buds and flowers of mulberry (*Morus* spp.), hackberry (*Celtis* spp.), Osage orange, elm, hawthorn (*Crataegus* spp.), wild cherries (*Prunus* spp.), sweet gum (*Liquidambar styraciflua*), Kentucky coffee-tree (*Gymnocladus dioica*), cottonwood (*Populus deltoides*), and honey locust (*Gleditsia triacanthos*), grape (*Vitis* spp.),

greenbrier (*Smilax* spp.), blueberry (*Vaccinium* spp.), and blackberry (*Rubus* spp.), as well as various insects and fungi were among the list of fox squirrel food items in the spring and summer (Koprowski 1991).

Nixon and Hansen (1987) found *S. n. rufiventer* to inhabit a variety of deciduous and mixed-forest habitats in Illinois, with the highest abundances in open forest stands (< 60% canopy cover) with an open understory (< 30% shrub crown closure). In prairie areas of Illinois, Brown and Yeager (1945) reported fox squirrel habitat to include hedgerows, timbered fencerows, small wooded bottoms, and farm woodlots. In Indiana, fox squirrels have been observed traveling greater than 500 m of hedgerows to use agricultural fields or retrieve cached nuts, as well as using roadside ditches hundreds of meters from any woodlot (Sheperd and Swihart 1995). These studies indicate that fox squirrels readily inhabit fragmented woodlands, and therefore an understanding of their use of fragmented habitat patches is needed for management of this subspecies.

Allen (1982) developed Habitat Suitability Index (HSI) models to assess optimal habitat for the fox squirrel in deciduous forest, deciduous forested wetlands, and deciduous tree savanna cover types throughout its range, except for the Outer Coastal Plain Forest and Southeastern Mixed Forest provinces. Brenner and Johnson (1989) used Allen's (1982) HSI model to evaluate the species-habitat relationship of fox squirrels in deciduous forest of western Pennsylvania and found that presence of agricultural land in close proximity to woodlots was an important factor in predicting areas of habitat use by fox squirrel. However, based on a report that fox squirrels occupy home ranges of 2 to 8 ha, the HSI equals 0.0 (entirely unsuitable) if less than 2 ha of

potentially suitable habitat are available. I was unable to find any literature reporting the application of Allen's (1982) HSI models to prairie areas such as Kansas where leaf nests often can be found in isolated fragments of less than 2 ha.

Because of the fox squirrel's ability to use a variety of foods, effectively traverse corridors for dispersal, and adapt to wooded areas with abundant edge, fragmented woodlands in an agricultural matrix appear to be suitable habitat for the fox squirrel (Sheperd and Swihart 1995). Metapopulation theory (Levins 1969) is based on the idea that ongoing extinction and recolonization ensures regional persistence of a species, and that degree of isolation, patch size and quality will influence the colonization rate of "satellite" patches. Habitat use is believed to be directly proportional to patch quality (Brown et al. 1994), which can increase with patch size (Hanski and Giplin 1991). Distance that squirrels will travel to a new patch is determined in part by the threat of predation (Lima and Valone 1986). Therefore, relatively large patches should experience a lower local rate of abandonment than small patches, and habitat patches nearest a source area should experience a higher immigration rate than patches further away (Hanski and Giplin 1991).

I used both abundance and presence/absence of leaf nests to assess habitat use by fox squirrels in a predominantly agricultural/grassland landscape in Coffey County, Kansas. I measured habitat, isolation, and connectivity variables of habitat patches to investigate how variation among habitat patches influences habitat use of fox squirrels. Also, I determined whether variation in use among habitat patches remained constant, by modeling data from one study site and applying it to the other study site. Lastly, my data

were applied to the HSI model developed by the U.S. Fish and Wildlife Service (Allen 1982) to evaluate its reliability.

Methods

The study area was located in Coffey County, Kansas (*Figure 1*), at the western edge of the Osage Questas. Coffey County is 6% forested with three predominant forest types: lowland plains hardwood, elm-ash locust, and elm-ash-cottonwood (Leatherberry et al. 1999). The study area consisted of two study sites that were selected based on my ability to get landowner permission and the following criteria: each study site had a predominantly agricultural/grassland landscape, a single, similarly sized riparian woodland 'core area', and similar tree species composition.

The two 15.5 km² (6 mi²) study sites contained Troublesome and Lebo creeks (*Figure 2*), which are located 19 km and 24 km east of Emporia, KS, respectively. They both are ephemeral streams that flow south into the Neosho River basin, which is a 6th order stream ranking 4th among Kansas river drainages for forested area (Leatherberry et al. 1999). In addition to a riparian area, each site contained numerous fragmented wooded patches scattered throughout the surrounding grassland and agricultural (soybeans, wheat, milo, alfalfa, and corn) landscape. Upland tree species such as elm, hackberry, and ash dominated both the riparian core areas and fragmented woodland patches. A majority of the wooded patches (approximately a third of which were planted linear strips at the turn of the 20th century as a means of erosion control for croplands and windbreaks for homesteads) were recent alterations relative to the core areas. Water sources were relatively small, man-made watering holes for cattle. Gravel roads determined the boundary for both study sites, as well as most of the 2.6 km² (1 mi²) sections within each site.

Figure 1. Location of study area in eastern Kansas.

Missouri

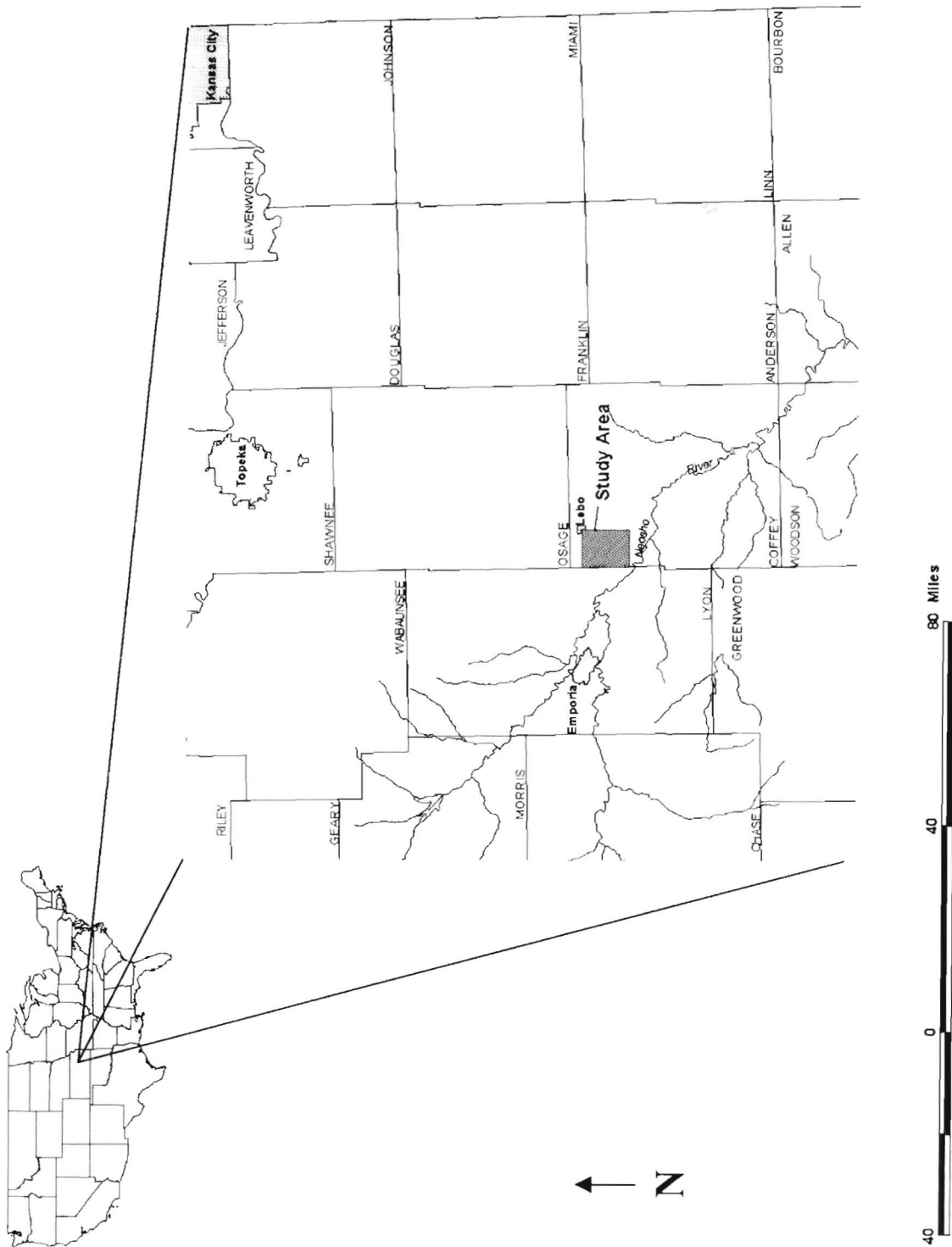
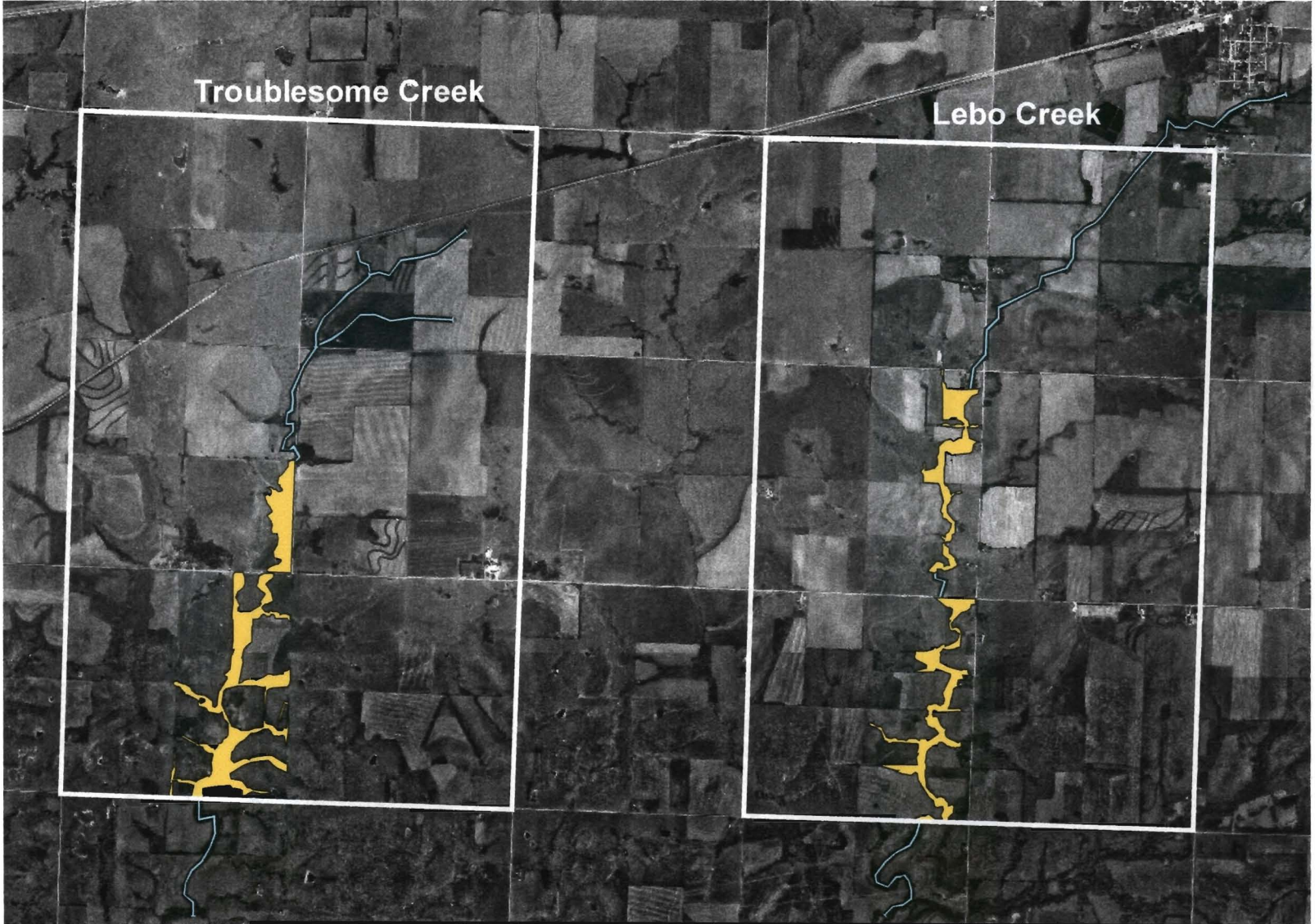


Figure 2. Location of the two 15.5 km² sites, Troublesome and Lebo creeks, in Coffey County, Kansas.

Troublesome Creek

Lebo Creek



Fox squirrels build leaf nests for shelter during warm months, as well as for raising young. Because individual fox squirrels build 3-6 leaf nests per year on average and can use as many as nine, leaf nest abundance cannot be used as an accurate index of fox squirrel densities (Koprowski 1991). However, several investigators have demonstrated that leaf nests serve as an indicator of habitat quality. Packard (1956) and Nixon and Hansen (1987) suggested that leaf nests were usually built in or near favored food trees. Edwards and Gwynn (1995) found structural characteristics of the nest tree and immediate habitat conditions to be important criteria for leaf nest placement. In Louisiana, McComb and Noble (1981) found that fox squirrels selected tree cavity nesting sites close to water. Thus, leaf nest abundance can be used as a measure of habitat use because the number of leaf nests built by one or more squirrels reflects the total amount of time spent using the habitat.

In March of 2000, I conducted leaf nest searches throughout both sites in an effort to quantify habitat use of fox squirrels. At each site, I searched all habitat patches thoroughly for leaf nests. A habitat patch (sampling unit) was defined as four or more trees with a closed canopy, covering an area of greater than 100m². I categorized each habitat patch as a woodlot, fencerow, hedgerow, or homestead. I recorded tree species and diameter at breast height (DBH) (cm) for each tree occupied by a leaf nest. Each patch was labeled on a digital orthophoto quad (DOQ) and assigned a number. In order to increase the chance of locating all leaf nests in the core areas (riparian woodlands), myself and two additional observers walked the entire length of core areas such that both sides of the creek could be searched simultaneously.










While conducting leaf nest searches, I spoke with landowners and examined crop residue to identify landuse from the previous summer (1999) in order to determine grain type availability at the time most leaf nests were being constructed. This allowed me to generate land cover maps for each sites (*Figures 3, 4*), by on-screen digitizing in ArcView™ 3.2 (Environmental Systems Research Institute, Inc., Redlands, CA) at 1:12000 on DOQs, in Universal TransMercator (UTM), NAD83 zone 15. The size of any polygon (shape file) can easily be determined by using ArcView™, allowing me to easily quantify landuse composition for each site. I also measured five isolation variables by using the land cover maps to view habitat patches remotely. Those variables were: linear distance from habitat patch to core area (DistCore), linear distance to nearest water source (DistWater), linear distance to nearest agricultural field (DistGrain), linear distance to nearest habitat patch, if any, serving as a ‘stepping stone’ to core area (DistStepstone), and linear distance to nearest habitat patch occupied by one or more leaf nests (DistOccupied). I ground truthed to confirm distances of less than 20 m. For those habitat patches on the periphery of the site, I chose to include isolation from previously mentioned land features, i.e. water sources, agricultural field, or core area, located outside of the study area that were closer to the peripheral habitat patches than those inside the site.

Additionally, I measured two variables to determine connectivity: the number of potential corridors associated with each habitat patch that could serve as travel lanes to an adjacent habitat patch (# Corridors), and the number of travel lanes that connected each habitat patch to a core area (# Connections). The presence of a corridor, e.g. fencerow or

Figure 3. Land use map of Troublesome site.



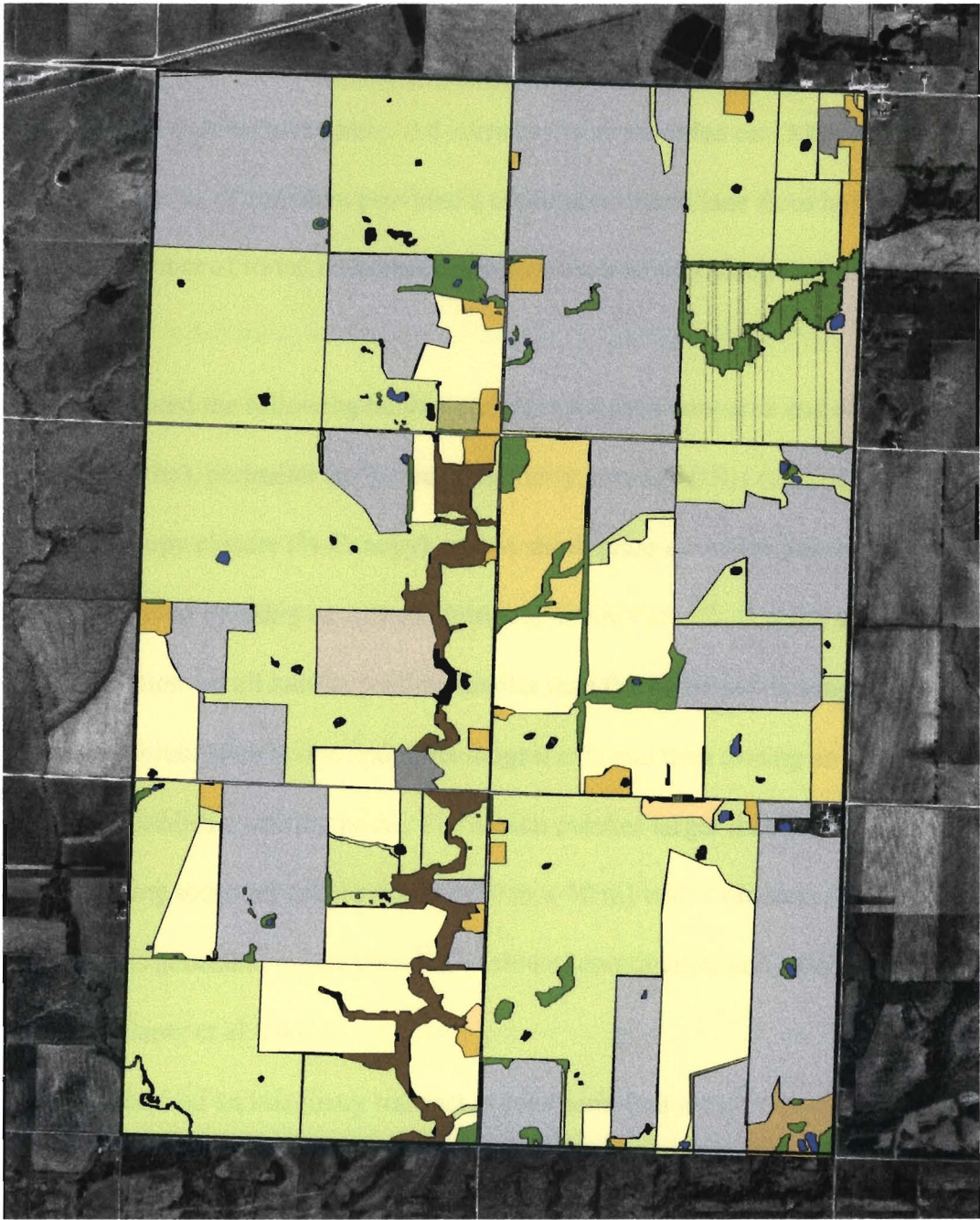
Landuse Components

- | | |
|---|--|
|  Patches |  Alfalfa |
|  Core Area |  Corn |
|  Ponds |  Fallow |
|  Homestead |  Grass |
|  Feedlot |  Milo |
|  Orchard |  Soybeans |
|  Rock Quarry |  Wheat-Fallow |

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Figure 4. Land use map of Lebo site.



Landuse Components

- | | |
|---|--|
|  Patches |  Alfalfa |
|  Core Area |  Corn |
|  Ponds |  Fallow |
|  Homestead |  Grass |
|  Feedlot |  Milo |
|  Orchard |  Soybeans |
|  Rock Quarry |  Wheat-Fallow |

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wooded draw, was determined by visually estimating the percent coverage of trees and shrubs between each habitat patch. All corridors were recorded on DOQs to determine which combination of corridors provided a continuous travel lane from habitat patch to core area. Number of travel lanes that connected each habitat patch to the core area was then tallied.

I measured the following habitat variables for each core area and all habitat patches: area (ha), perimeter (m^2), tree community, average DBH (cm) of overstory trees (DBH), % canopy closure (% Canopy), and % shrub/grass cover (% Shrub/Grass). Patch size was measured by using on-screen digitizing in ArcViewTM. I chose a single sampling location for all habitat patches smaller than 0.2 ha by positioning myself at the edge of the habitat patch at one end of its longest axis and then tossing an object over my shoulder to establish a starting point. For habitat patches larger than 0.2 ha, I determined habitat sampling locations (approximately 30 m x 30 m) with a randomized series of point locations generated in ArcViewTM, a table of coordinates, and a GPS unit (Garmin GPS III) (DeSanty et al. 2001).

I established an imaginary transect at each sampling location and eight random sampling points were generated along each transect. I measured percent shrub cover at each of the eight sampling points (stations) along each transect with a Daubenmire frame (Daubenmire 1959). Since knee-high Virginia wild rye (*Elymus virginicus*) dominated the understory within both study sites, I chose to measure 'percent understory cover' of shrubs and grasses (> 30 cm in height), rather than use the traditional 'percent shrub cover' measurement. I recorded distance to nearest tree, tree species and DBH, in each of

four quadrants, at four sampling points (1st, 3rd, 5th, and 7th) along each transect (Krebs 1999). Dead trees or those trees with a DBH of less than 8 cm were not measured (Leatherberry et al. 1999). Percent canopy cover also was obtained at the 1st, 3rd, 5th, and 7th sampling points by using a spherical densiometer (Lemmon 1957). By graphical examination of variation in habitat variables, 5% and 10% of the area of core and habitat patches, respectively, were determined to be adequate habitat samples. I measured area, perimeter, and habitat variables in each core area for the purpose of study site comparisons, but core data were not incorporated into habitat use analyses.

I generated an HSI value for each habitat patch with the winter food and cover/reproduction life requisite components of the HSI developed by the U.S. Fish and Wildlife Service (Allen 1982). The five variables incorporated into the HSI model include: percent canopy closure that produce mast (V_1), distance to available grain (V_2), average DBH of canopy trees (V_3), percent tree canopy closure (V_4), and— percent shrub crown cover (V_5). I did not measure V_1 due to the paucity of hard mast producing trees within the study area. However, as a surrogate of V_1 , I used habitat sampling data to calculate percent of hard mast species per patch. Additionally, given that grasses such as Virginia wild rye are a considerable contributor to the understory of the landscape being investigated, I feel that percent shrub/grass cover is an acceptable substitute of V_5 .

The model was scaled to produce an index value between 0.0 (unsuitable habitat) and 1.0 (optimal habitat) based on the equations:

$$\text{Winter Food} = (3 * V_1 + V_2) / 4$$

$$\text{Cover/Reproduction} = (V_3 * V_4 * V_5)^{1/3}.$$

The equation for the winter food component of Allen's (1982) HSI model had "3" in the denominator. I assumed the number "3" is a typographical error because the equation would produce values in excess of 1.0 without "4" being in the denominator. The numerator was expressing the weighted average of V_1 as being three times more important than V_2 . The denominator of the equation was generated by adding the weighted value for V_1 to V_2 ($3 + 1 = 4$). However, it appeared that both Brenner and Johnson (1989) and Seng and Wiggers (1991) might have used the incorrect equation, as neither publication alluded to the error. Because HSI values needed to be generated for each habitat patch (Allen 1982), the application of Allen's models were simplified by generating mathematical equations that could be entered into a SAS (1990) program (DeSanty et al. 2001 *In prep*). I employed global non-metric multidimensional scaling using a Bray-Curtis distance coefficient to obtain a quantitative measure of tree community similarity among habitat patches by scaling tree density per species per patch, to reduce tree community structure to a single dimension that could be used in multiple regression (TreeCommunity values are listed in *Appendix II*). I used stepwise multiple regression (Zar 1996) to determine which variables could be used as predictors of leaf nest abundance, and linear discriminant function analysis (Zar 1996) to determine whether presence or absence of leaf nests served as a better predictor of habitat use by fox squirrels than leaf nest abundance. HSI values were then computed for each patch to determine whether or not the HSI model is more reliable at predicting habitat use than those predictive variables selected from multiple regression and discriminant analysis procedures.

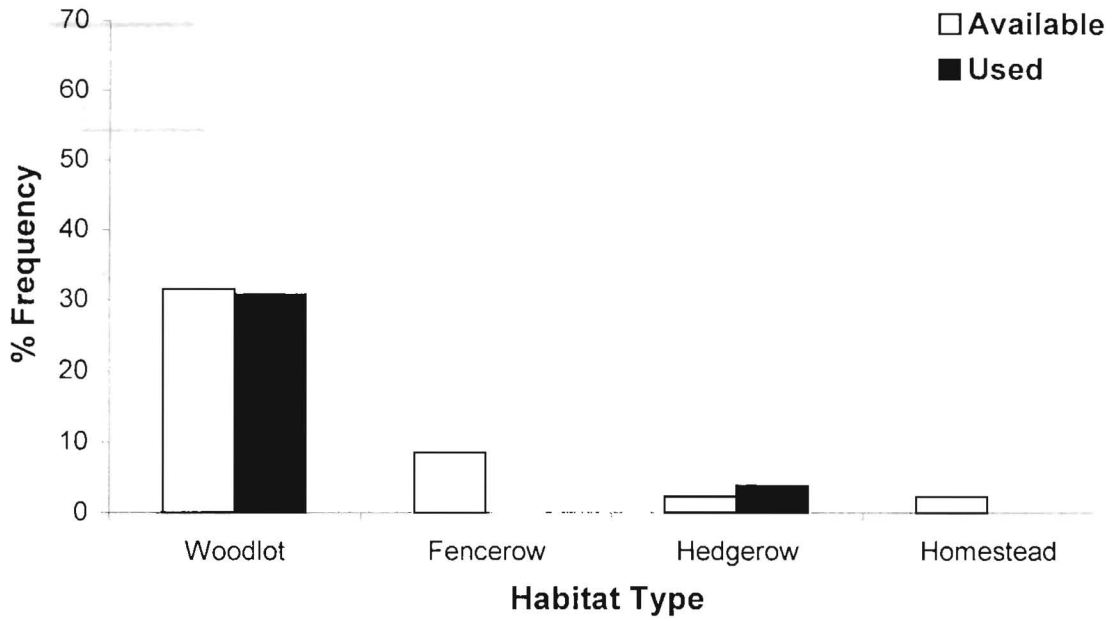
Results

Leaf nest searches discovered 39 and 172 leaf nests in the habitat patches of Troublesome and Lebo creek sites, respectively, and 123 leaf nests were found in the core area of Troublesome, while 61 were located in Lebo core area. Nine of the 58 (16%) (0.09 ± 0.16) habitat patches at Troublesome were occupied by one or more leaf nests. Two of these patches were larger than 2 ha, and contained 36% (0.36 ± 0.15) of the total leaf nests. At Lebo, 26 of the 72 (36%) (0.36 ± 0.11) habitat patches were occupied by one or more leaf nests. Three patches were larger than 2 ha, and contained 52% (0.52 ± 0.07) of the total number of leaf nests. Habitat patches for both study sites combined ranged in size from 0.01-12.9 ha, with a mean of 0.54 ha. Only 4.8% (0.05 ± 0.01) of the landscape was wooded, of which 50% was core area and 49% constituted fragmented habitat patches. By far the most common habitat patch type at both study sites was woodlot. Habitat patch types were used in proportion to availability at both study sites ($P > 0.10$) (*Figure 5*). Some general comparisons of landscape characteristics between the study sites include total core area slightly larger at Troublesome than Lebo; total patch area considerably larger at Lebo; a higher percentage of grassland than tillage in Troublesome, while the opposite is true for Lebo; homesteads more prevalent at Lebo (28) than at Troublesome (6); and soybean the primary crop type for both study sites (*Table 1*).

Girths of trees (DBH) used for leaf nest construction by fox squirrels suggested that larger trees were used in greater proportion than were available within both core areas ($0.005 < P < 0.01$) and habitat patches ($0.001 < P < 0.005$) (*Figures 6, 7*). Trees less than 38 cm (DBH) were approximately seven times (44%) more abundant than the

Figure 5. Results of patch type available versus used for Troublesome (A) and Lebo (B) sites.

A



B

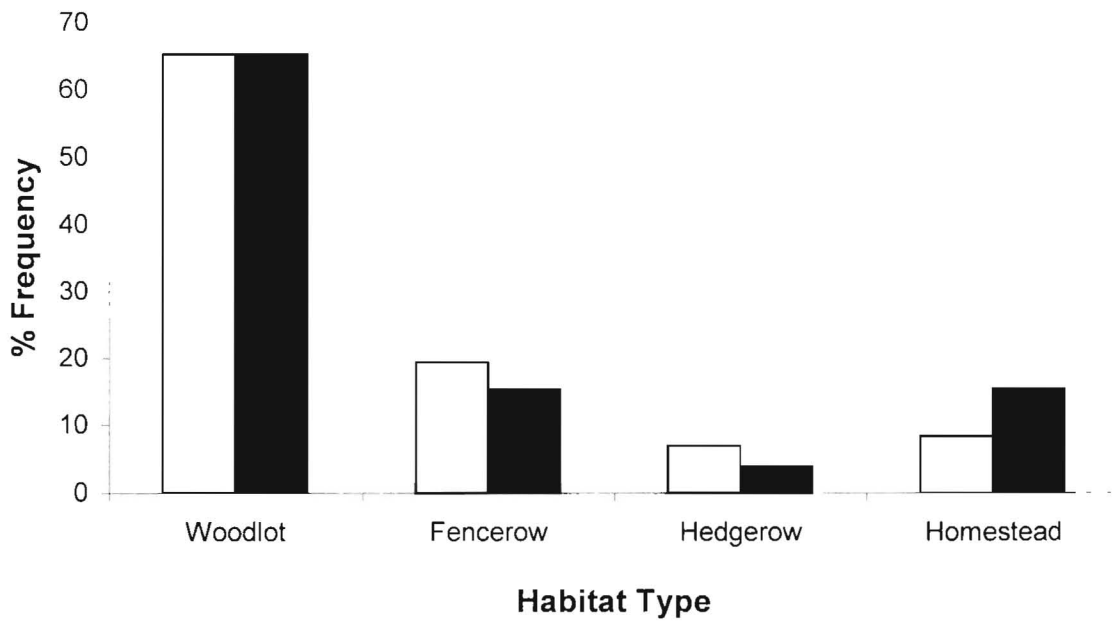


Table 1. Land uses of Troublesome and Lebo sites.

Landuse	Troublesome Creek		Lebo Creek	
	Hectares	%	Hectares	%
Core	41.3	2.7	33.5	2.2
Patches	25.5	1.7	44.6	2.9
Homestead	9.0	0.6	25.8	1.7
Feedlot	2.4	0.2	3.5	0.2
Orchard	1.1	0.1	2.4	0.2
Rock quarry	0.0	0.0	7.3	0.5
Water	7.9	0.5	8.5	0.6
Grass	760.6	50.6	664.5	43.6
Tillage	655.7	43.6	732.9	48.1
Soybeans	377.0	25.1	447.4	29.4
Milo	111.0	7.4	218.3	14.3
Corn	23.6	1.6	33.9	2.2
Alfalfa	18.8	1.3	6.1	0.4
Fallow	55.2	3.7	0.0	0.0
Wheat-Fallow	70.1	4.7	27.2	1.8

Figure 6. Girths of trees (DBH) used by fox squirrels for constructing leaf nests in core areas of Troublesome (A) and Lebo (B) sites.

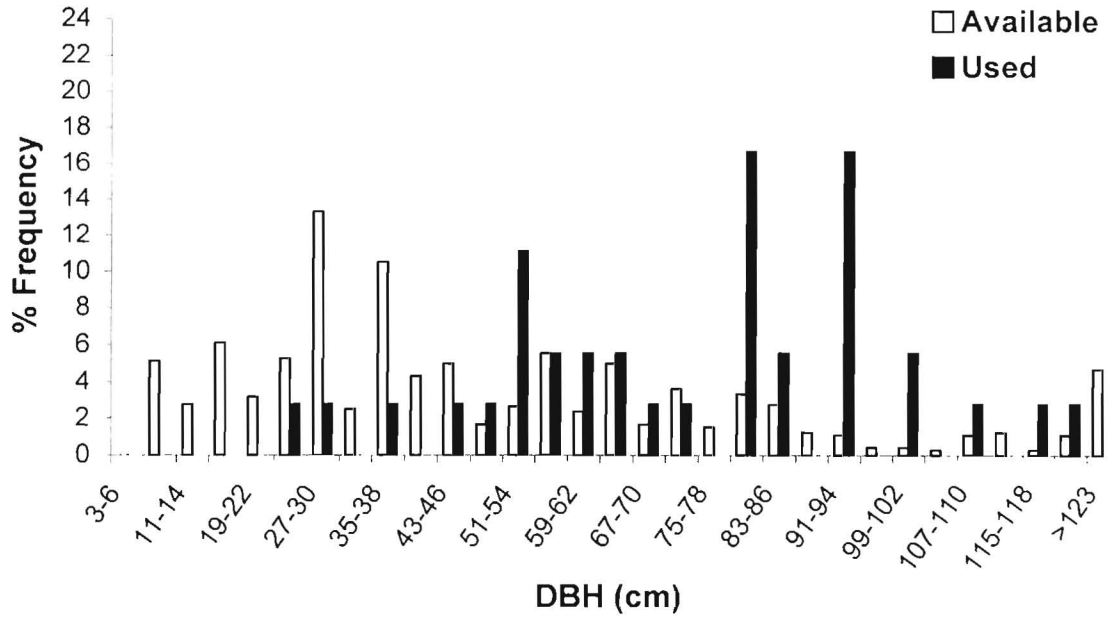
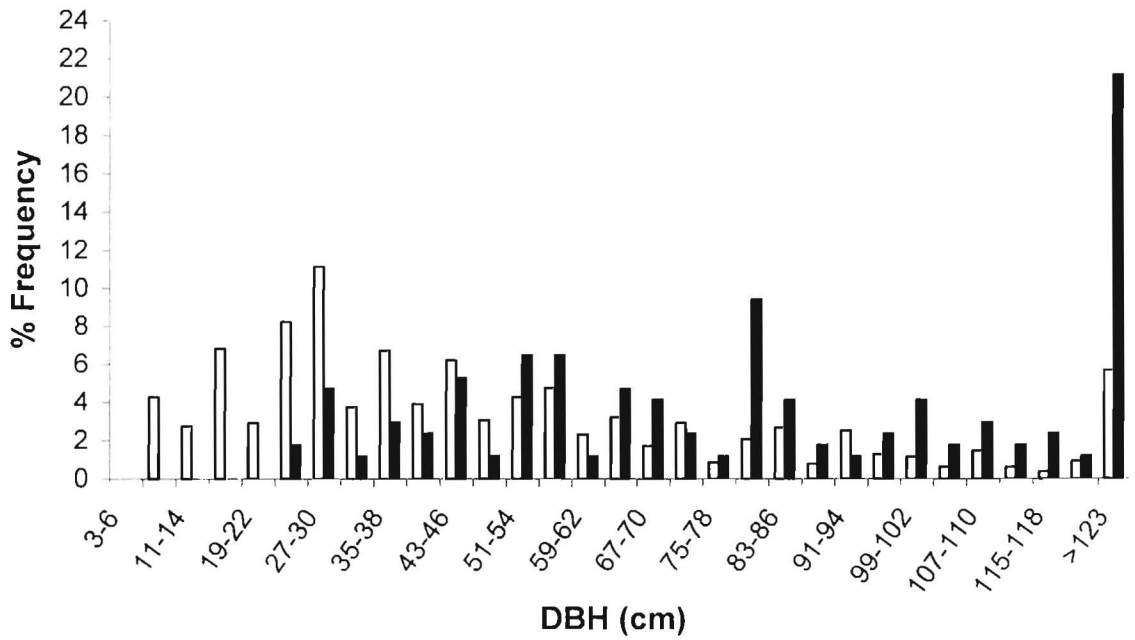
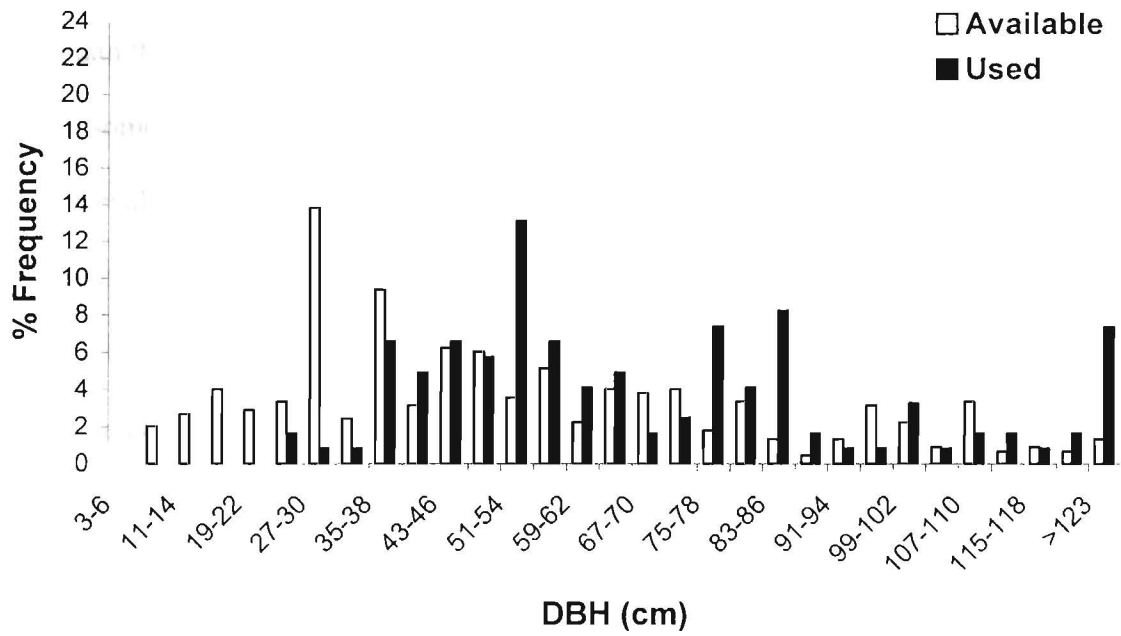
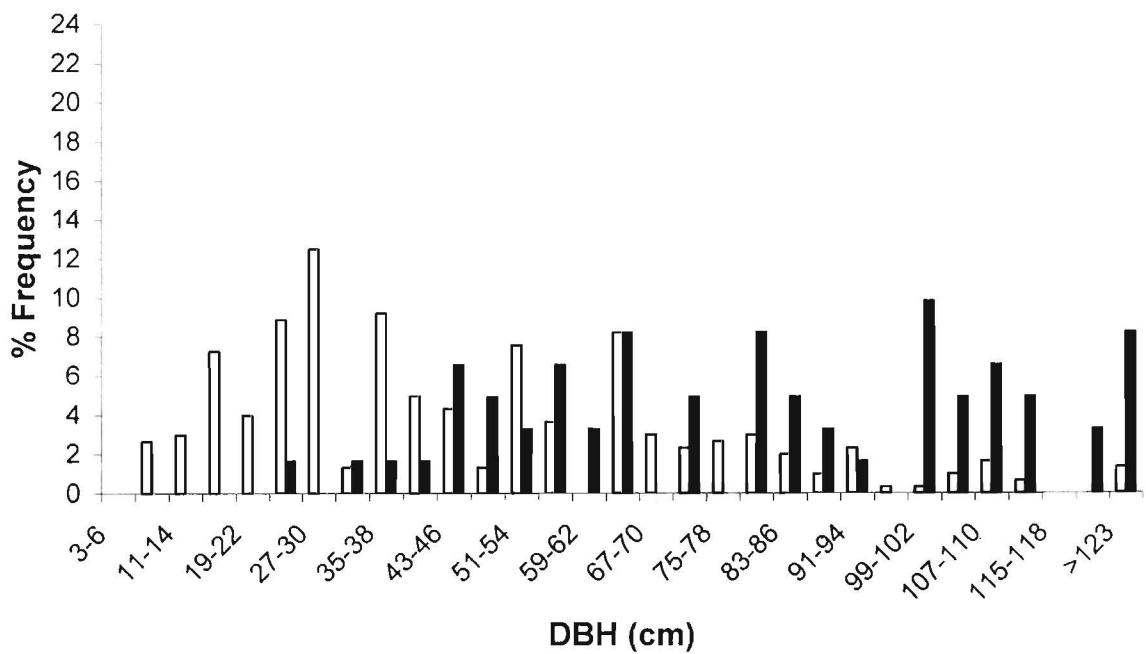
A**B**

Figure 7. Girths of trees (DBH) used by fox squirrels for constructing leaf nests in patches of Troublesome (A) and Lebo (B) sites.

A**B**

proportion used (6%), and trees less than 53 cm (DBH) were three times more abundant (60%) than the proportion used (22%), when averaged among the four habitat areas (Troublesome core, Lebo core, Troublesome patches, and Lebo patches).

Results of tree species use for leaf nest construction suggested that fox squirrels choose locust and elm in different proportions than were available ($0.01 < P < 0.025$) (*Table 2*). Locust trees (approximately 99% of which were honey locust), which contributed 53% of the chi-square value, were selected in greater proportion than were available. Elms, which contributed 32% of the chi-square value, were selected in less proportion than available in the environment.

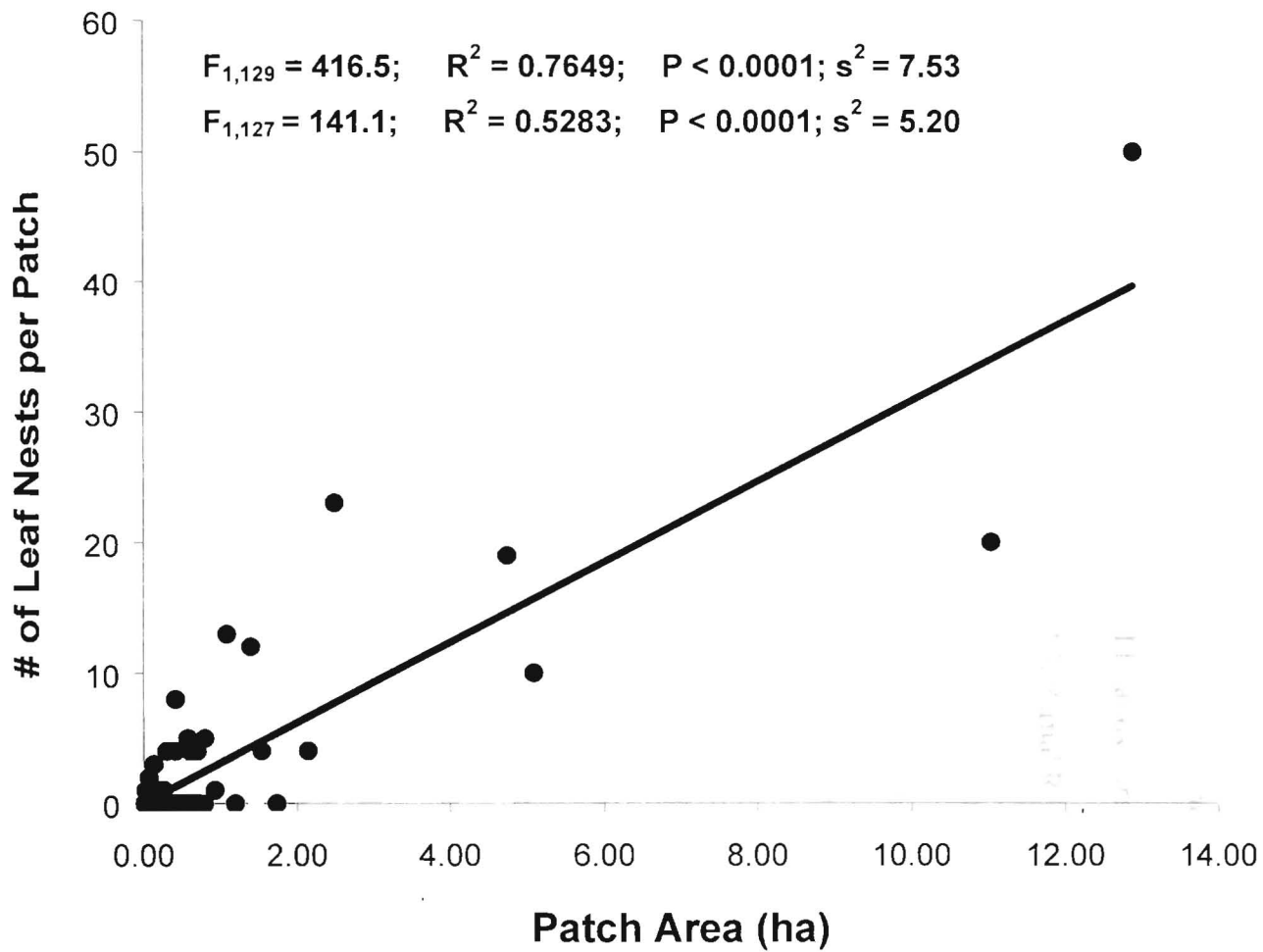
Data were pooled from each site and stepwise multiple regression was used to determine which of the 12 explanatory variables were good predictors of leaf nest abundance (SAS 1990). Area ($F_{1,129} = 416.5$, $R^2 = 0.7649$, $P < 0.0001$, $s^2 = 7.53$) was selected as the most statistically powerful single-variable model (*Figure 8*). The two-variable model, Area* # Connections ($F_{2,129} = 220.5$, $R^2 = 0.7764$, $P < 0.0001$) also had a significant partial F ratio of 0.46. Unfortunately, only four of the 130 habitat patches were larger than 3.0 ha, and there was a lack of patches between 5-11 ha. When the two largest patches were omitted from analysis (Area ($F_{1,127} = 141.1$, $R^2 = 0.5283$, $P < 0.0001$, $s^2 = 5.20$)) the slope of the regression line was nearly identical, but the R^2 value dropped considerably. This suggested that the two large patches were highly influential data points, unrealistically inflating the R^2 value. The smaller s^2 value obtained when the two large patches were dropped from the analysis further supports this premise.

Table 2. Preference of tree species for leaf nest construction by fox squirrels. Data were pooled for all four areas (Troublesome core area, Troublesome patches, Lebo core area, and Lebo patches). Trees were only identified to genus because leaves were absent at time of identification.

Tree Species	# Trees Avail.	% Trees Avail.	# Trees Used	% Used
hackberry (<i>Celtis</i>)	546	19.5	71	18.0
elm (<i>Ulmus</i>)	500	17.8	46	11.7
Osage orange (<i>Maclura</i>)	431	15.4	65	16.5
locust (<i>Robina, Gleditsia</i>)	324	11.6	82	20.8
ash (<i>Fraxinus</i>)	243	8.7	37	9.4
mulberry (<i>Morus</i>)	183	6.5	16	4.1
walnut (<i>Juglans</i>)	178	6.4	28	7.1
willow (<i>Salix</i>)	132	4.7	6	1.5
cedar (<i>Juniperus</i>)	116	4.1	11	2.8
box elder (<i>Acer</i>)	51	1.8	20	5.1
catalpa (<i>Catalpa</i>)	49	1.7	2	0.5
cottonwood (<i>Populus</i>)	33	1.2	1	0.3
pecan (<i>Carya</i>)	6	0.2	1	0.3
hickory (<i>Carya</i>)	4	0.1	0	0.0
redbud (<i>Cercus</i>)	3	0.1	0	0.0
maple (<i>Acer</i>)	2	0.1	4	1.0
pine (<i>Pinus</i>)	1	0.0	3	0.8
crabapple (<i>Pyrus</i>)	1	0.0	0	0.0
bur oak (<i>Quercus</i>)	0	0.0	1	0.3

Figure 8. Results of multiple regression analysis for predicting leaf nest abundance.

Area ($F_{1,129} = 416.5$, $R^2 = 0.7649$, $P \geq 0.0001$, $s^2 = 7.53$) was selected as the best one-variable predictive model.



Because using Area to predict leaf nest abundance was marginally accurate (Area explained only 50% of the variation in patches occupied by leaf nests), linear discriminant function analysis was used to generate predictive models of leaf nest presence and absence. The variable screening process of stepwise discriminant function analysis (SAS 1990) selected four variables with significant partial F ratios: Area ($F_{1,122} = 16.9$, Partial $R^2 = 0.1185$, $P < 0.0001$), # Connections ($F_{1,122} = 12.7$, Partial $R^2 = 0.0921$, $P < 0.0005$), DBH ($F_{1,122} = 2.5$, Partial $R^2 = 0.0196$, $P < 0.1178$), and % Canopy ($F_{1,122} = 2.3$, Partial $R^2 = 0.0181$, $P < 0.1344$). In order to validate the model, I arbitrarily selected Lebo site data to be modeled and applied to the data set of Troublesome site. The model accurately predicted those patches unoccupied by leaf nests 98% of the time (48 of 49 patches), but was able to predict the presence of leaf nests with only 33% (3 of 9 patches) accuracy (*Table 3*). To verify that the model was not misclassifying occupied patches due to low patch occupancy rate (9 of 58 patches were occupied by leaf nests in Troublesome site), I modeled Troublesome site data and applied it to Lebo site dataset (26 of 72 patches were occupied). The model accurately predicted those patches unoccupied by leaf nests 93% of the time, but was able to predict the presence of leaf nests with only 27% of the time. Results of these analyses did not change by including or omitting the two “influential” data points. Additionally, applying the one, two, or three-variable models (to either site) yielded results consistent with that of the four-variable model in *Table 3*.

Figures 9 and 10 show the results of applying my data to Allen’s (1982) HSI model. I expected that for those patches occupied by leaf nests a relatively high HSI value would be assigned relative to those unoccupied by leaf nests. Values of less than

Table 3. Results of discriminant function analysis for predicting presence and absence of leaf nests. Area, # Connections, DBH, and % Canopy cover were selected as the best predictor variables. Lebo site data was modeled and applied to Troublesome site data.

		LEAF NESTS OBSERVED		
		Absent	Present	Total
LEAF NESTS PREDICTED	Absent	48 97.96	1 2.04	49 100
	Present	6 66.67	3 33.33	9 100
	Total	54	4	58
	Percent	93.1	6.9	100

Figure 9. Results of combining data from both sites and applying them to the Winter Food life requisite component of the Habitat Suitability Index (HSI) model (Allen 1982). The model was scaled to produce index values between 0.0 (unsuitable habitat) and 1.0 (optimal habitat) and plotted against number of leaf nests occupying each patch. Those patches occupied by more than 10 leaf nests are indicated as being equal to 10 to allow for the best fit of the graph. Symbols represent number of leaf nests (● = 1, ■ = 2, ▲ = 3, Δ = 6, □ = 17, ○ = 84).

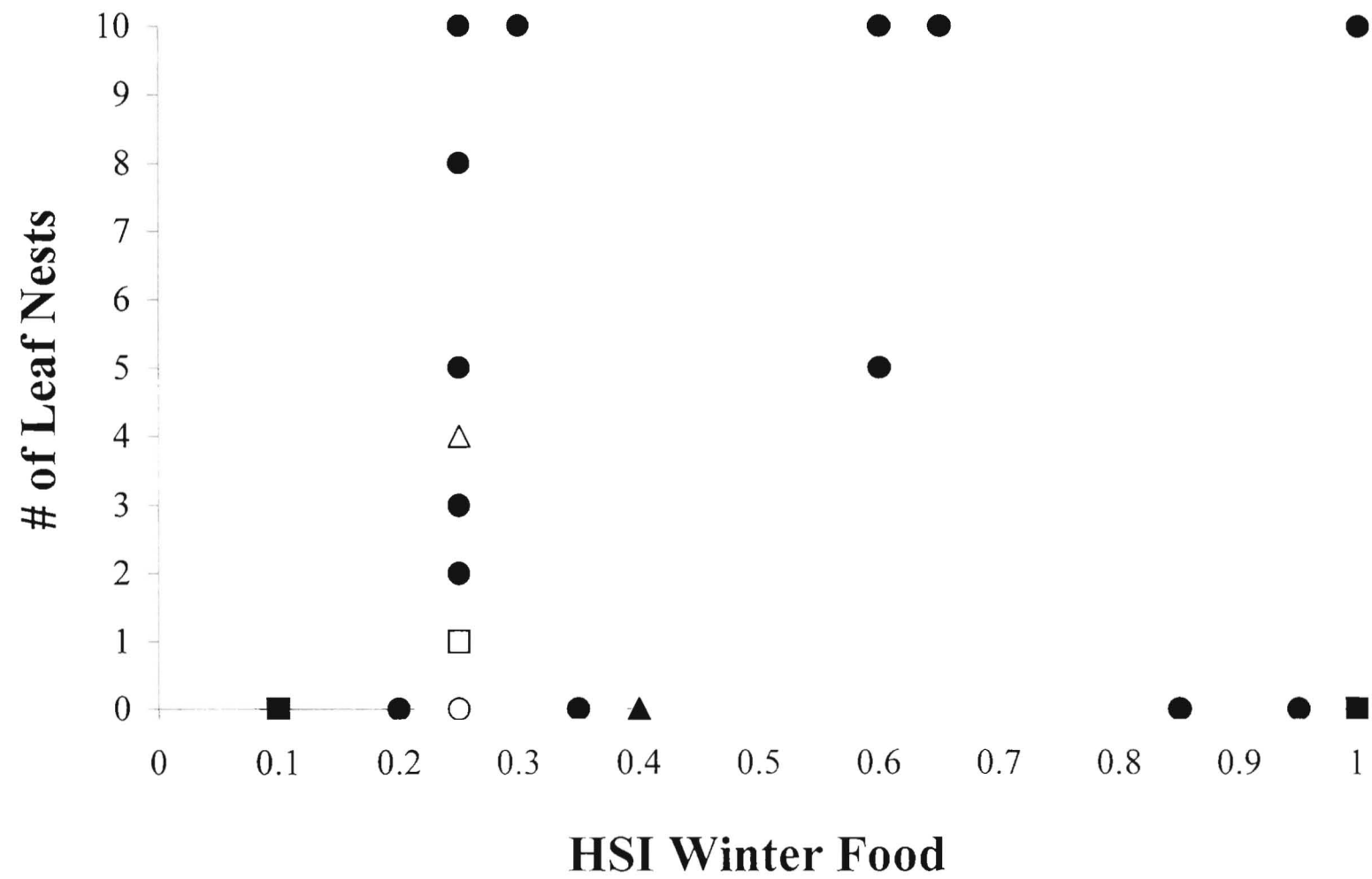
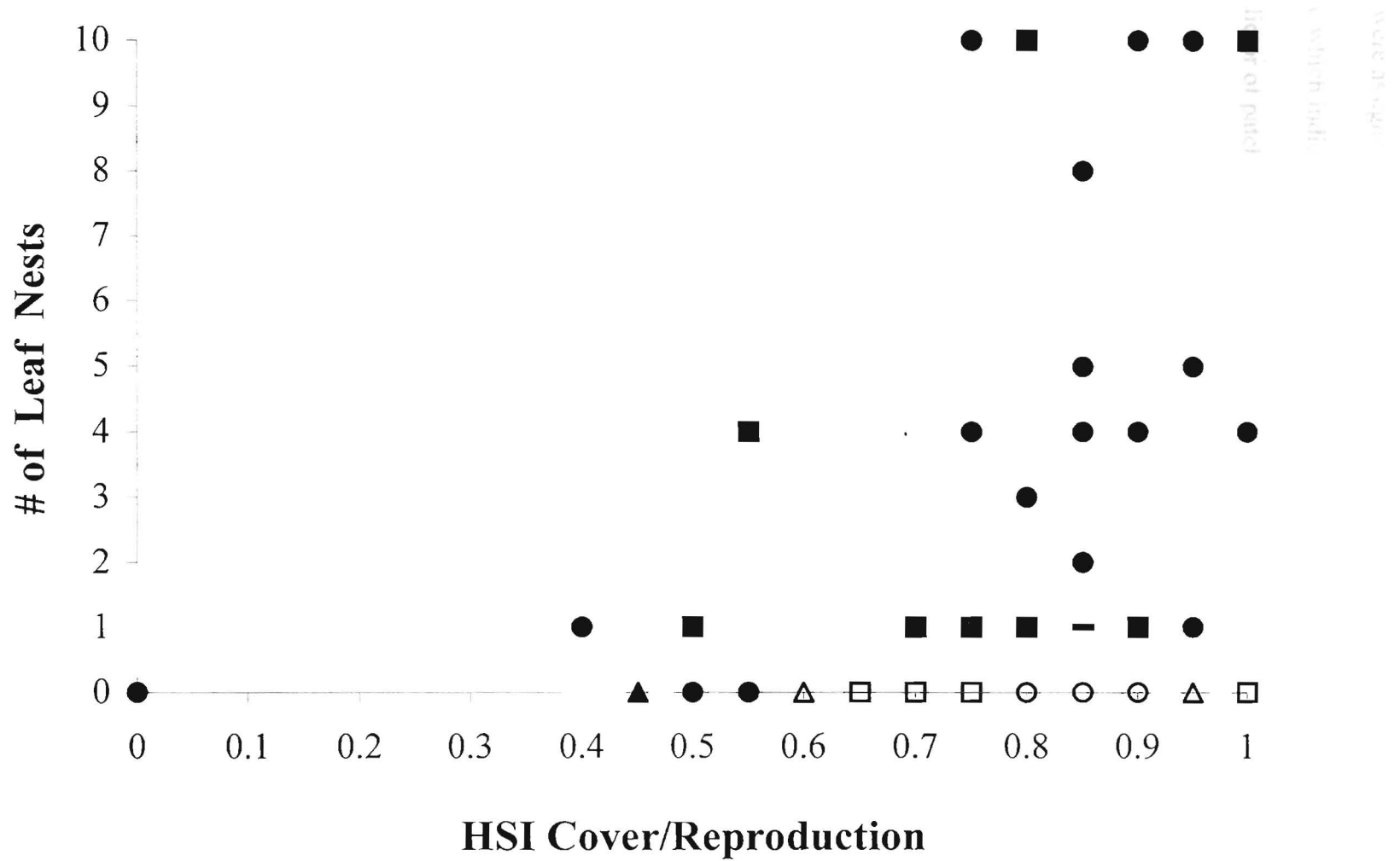


Figure 10. Results of combining data from both sites and applying them to the Cover/Reproduction life requisite component of the Habitat Suitability Index (HSI) model (Allen 1982). The model was scaled to produce index values between 0.0 (unsuitable habitat) and 1.0 (optimal habitat) and plotted against number of leaf nests occupying each patch. Those patches occupied by more than 10 leaf nests are indicated as being equal to 10 to allow for the best fit of the graph. Symbols represent number of observations (● = 1, ■ = 2, ▲ = 3, — = 5, Δ = 6, □ = 8, ○ = >8).



0.3 were assigned to 31 of the 35 (88.6%) occupied patches identified within the study area, which indicated that the Winter Food component of the model (*Figure 9*) was a poor predictor of patches occupied by one or more leaf nest. However, the model accurately assigned low HSI values to 88 of the 96 (91.7%) unoccupied patches. Conversely, the Cover/Reproduction component of the model (*Figure 10*) accurately assigned relatively high values (≥ 0.75) to 27 of 35 (77%) occupied patches, while 89 of the 96 (92.7%) unoccupied patches were assigned HSI values less than 0.6, which indicated this component of the model to be relatively accurate at predicting those patches occupied by leaf nests, but extremely poor at predicting those patches unoccupied by leaf nests.

Discussion

Most investigations of species response to forest fragmentation by scansorial squirrels have involved Eurasian red squirrel, *S. vulgaris*. In Italy, woodlot size at one study area and distance to nearest 'source-area' in the second study area were the best explanatory variables of the presence of red squirrels (Celada et al. 1994). Woodlot size, area of woodlot covered with coniferous trees, and distance to larger (> 30 ha) woodland best predicted red squirrel presence in 50 woodlots ranging in size from 0.5-13.0 ha, in The Netherlands (Verboom and van Apeldoorn 1990). Wauters et al. (1994) found space use and home range size of red squirrels in fragmented habitat to be strongly influenced by woodlot size and structure. In Sweden, neither patch size nor degree of isolation were significant predictors, only proportion of spruce (*Picea*) within a habitat fragment influenced a red squirrel density index (Delin and Andrén 1999). Rodriguez and Andrén (1999) used patch size (> 10 ha) and distance to source area (< 600 m) to predict red squirrel occupancy of patches in 90% of cases, but predictive power decreased to 17% in those patches less than 10 ha, which suggested that factors such as demography or habitat quality explained patch occupancy in very small and isolated fragments.

Fitzgibbon (1993) found similar responses to habitat fragmentation by gray squirrels (*S. carolinensis*). Using 68 deciduous woodland patches ranging from 0.2-12.5 ha in England, the author demonstrated that presence of gray squirrels could best be predicted by the occurrence of larger patches (> 5 ha), that were close to a neighboring patch of at least 5 ha, which contained oak, beech (*Fagus*), or hazel (*Corylus*) trees, with highly dense nearby hedgerows. No other habitat or isolation variable, not even

proportion of woodland in a landscape (as suggested by Andrén 1994), improved the fit of the model. Interestingly, woodland patch size was not an important factor determining density of dreys (leaf nests), instead, age of the woodland patch and distance to nearest patch of less than 5 ha influenced drey abundance. In Illinois, Nixon et al. (1978) showed that proportion of forested area in a landscape accounted for 76% of the variance in a 54 variable discriminant function analysis of gray squirrel habitat preference.

In four of the seven previously mentioned studies, patch size and isolation significantly influenced the response of species to habitat fragmentation. In my study, although patch size was selected by both regression and discriminant analysis as the best variable for predicting patch occupancy, 83% of the occupied patches were smaller than the expected 2 ha minimum patch size for fox squirrels suggested by the HSI model (Allen 1982), and 63% were smaller than the minimum patch size (> 0.6 ha) recommended for Midwestern populations (Nixon 1968; Weigl et al 1992). None of the three isolation variables (DistCore, DistStepstone, DistOccupied) significantly improved the fit of either of my models.

However, other authors have suggested that species distribution and abundance can not be explained entirely by the processes of colonization and extinction of populations of species occupying isolated habitat patches. For example, Andrén (1994) demonstrated that the importance of patch size and isolation was influenced by the degree to which the landscape was fragmented (the proportion of suitable habitat in a landscape), such that negative effects of patch size and isolation might not occur until only 10-30% of the original habitat exists.

Two assumptions of metapopulation dynamics (that suitable habitat patches are separated by inhospitable habitat (divided landscape) and that each habitat patch is being occupied by its own local population) are clearly violated in my study. Sixty-four percent of the habitat patches identified within the study area were connected to the core area by fencerows and hedgerows, and 77.8% of the patches were smaller than 0.4 ha, which is more than likely too small of an area to support a local population (Allen 1942; Brown and Yeager 1945; Packard 1956; Nixon and Hansen 1987). Although only 4.8% of my study area was forested, the abundance of fencerows and hedgerows might have alleviated the influence of isolation.

Andrén (1994) suggested that incorporating patch size and isolation principles with individual scale (e.g. home range) considerations might better explain a species' distribution and abundance in fragmented landscapes. Alternative mechanisms include species-specific responses such as habitat preference, constraints due to home range size, dispersal ability (Mills 1996; Rosenblatt et al 1999), spatiotemporal distribution of resources, predators and competitors, and sociological response to changing conditions (Andrén 1994). Although Rosenblatt et al. (1999) found that mammalian species richness was positively correlated with area, he concluded that the majority of mammalian species are habitat generalists, moving freely across the agricultural landscapes of Illinois (of which 81% is in agriculture), and were not being limited in distribution by habitat fragmentation. However, an exception to the trend occurred in woodland rodents, which seemed to be limited in distribution by patch isolation.

Zollner (2000) demonstrated that behavioral mechanisms such as “perceptual

range” might be important components of dispersal success in fragmented landscapes. By translocating fox squirrels and releasing them in large, harvested agricultural fields at various distances from a woodlot, the author was able to determine that fox squirrels have a perceptual range of 300-500 m. Additionally, the influence of landscape composition, e.g. degree of isolation among patches, might be determined by a species’ perceptual range. Using radiotelemetry to study spatial dynamics of fox squirrel habitat use in fragmented landscapes of Indiana, Sheperd and Swihart (1995) found no inter-patch movement among ten woodland sites ranging from 0.8 –32.2 ha in size. Within patches, squirrel movements were restricted compared to those of individuals occupying large, continuous forest tracts. However, the authors concluded that fox squirrels appeared to perceive the surrounding agricultural matrix as hospitable, 2.6% of location points placed squirrels outside the woodlots, where they were observed caching mast or consuming crop residue within 60 m of woodland edge. Also, fox squirrels were observed using roadside ditches hundreds of meters from any woodlot, as well as traveling through hedgerows 200-600 m from the resident woodlot. During a seven year study of southern fox squirrels in North Carolina, 35 of the 53 marked and recaptured fox squirrels were caught within 70 m of the initial capture location after several months. Because the authors were not able to relocate the squirrels in a several week period following the initial capture, the authors assumed that these squirrels were exhibiting opportunistic use behaviors by temporarily leaving their patch to use food or nesting resources elsewhere, and then returning to the patch (Weigl et al. 1992). Similarly, Fitzgibbon (1993) suggested that where gray squirrels occupied patches of 0.5 ha, it was highly likely that

more than one patch was being used because estimates of their domain size are greater than 1 ha. In my study, fewer than 12% of the patches were isolated by more than 450 m. Given that 77.8% of the patches (63% of occupied patches) within my study sites were less than 0.4 ha, individual fox squirrels could be using multiple patches.

HSI models are designed to provide a quantitative measure of habitat preference. To my knowledge, the HSI model for fox squirrels has been examined only twice. Using four woodlots in Pennsylvania, Brenner and Johnson (1989) found the cover/reproduction life requisite component more important than winter food in determining suitability, and presence of agricultural land nearby was important in determining occupancy. Studying fox squirrels occupying areas of greater than 50% woodland, and greater than 600 m from agricultural fields in Missouri, Seng and Wiggers (1991) found no correlation between HSI indices and fox squirrel density estimates. They concluded that the relationship between specific HSI variables and habitat suitability values were incorrect, that additional habitat variables should be added or substituted, and that other factors besides habitat variables influence fox squirrel density, e.g. hunting.

Prior to collecting data, I felt that the HSI model was not applicable to my study area, to Kansas, or to most other states in the Great Plains, primarily because the model assumed that habitat patches smaller than 2 ha would not be suitable habitat, but also because the weighted average assigned to the winter food component assumed a reliance on mast crop by fox squirrels, which is not necessarily the case in Kansas. That high values (≥ 0.75) from the cover/reproduction component were given to 91.7% of patches smaller than 2 ha, and 51.6% of the patches unoccupied by leaf nests, and low values

(< 0.30) were given to most (89%) of the patches occupied by leaf nests, indicated that the HSI model was too general to apply to my study area, and modifications were needed to improve the predictability of the model. Several modifications might improve the accuracy of predicting habitat suitability for fox squirrel in predominantly agricultural/grassland areas: 1) incorporating area into model as a variable of the equation, rather than leaving it an assumption, 2) removing the weighted average assigned to the food variable because of the paucity of mast producing trees in fragmented, upland prairie habitats, and 3) incorporating other food sources such as Osage orange and honey locust into the model. Of the five habitat variables that I chose to measure and the measurements taken at leaf nest locations (DBH and species of occupied trees), only three seem to be indicators of habitat preference: 1) mean DBH, 2) % canopy closure of patches (both of which are cover/reproduction variables of the HSI model), and 3) the selection of trees with larger DBH for leaf nest construction. The selection of larger trees has been previously documented (Nixon and Hansen 1987). Brown and Batzli (1984) demonstrated that tree size distribution did not influence fox squirrel habitat preference. Fox squirrel tree species preferences for constructing leaf nests have been reported; black oak (*Quercus velutina*) and white pine (*Pinus strobis*) (Allen 1942), and white oak (*Quercus alba*) and beech (*Fagus* spp.) (Nixon and Hansen 1987). Brown and Yeager (1945) found no tree species preference for leaf nest construction. In my study, fox squirrels seemed to prefer locust, and used elm in less proportion than were available. Taylor (1973) found the presence of Delmarva fox squirrels to be associated with the presence of water. However, this meant either that the squirrels were more likely to

select swampy areas, that presence of water correlated indirectly with inaccessibility to logging (the primary reason postulated for the subspecies decline), or that river tributaries are bordered by agricultural estates. Although I was expecting proximity to water to be selected by the analyses as a significant predictor of fox squirrel distribution in my study, it was not. Perhaps the lack of correlation was due to the majority of patches (85.4%) having a water source within less than 400 m, which is within the perceptual range suggested by Zollner (2000). Unfortunately, as Allen (1942) pointed out, “location, and probably factors of suitability known only to a squirrel are more important than species (of trees for nesting)”.

Although the fox squirrel has not been studied extensively at the landscape level, some of the species-specific responses mentioned earlier, i.e. constraints due to home range size, dispersal ability, and spatiotemporal distribution of resources, have been well documented as influencing distribution and abundance of fox squirrels. For example, Brown and Yeager (1945) suggested that fox squirrels might cross woodlands or open fields for a distance of 3-5 km while foraging, and that local shifts followed specific food availability: elm lowlands (February-July), mulberry and corn (mid-summer/fall), and oak-hickory areas (fall-winter). If all seasonal foods are available locally, they might stay within a few hundred m² the entire year. Allen (1942) observed a female fox squirrel using one red maple (*Acer rubrum*) tree as a center of activity for two years. Armitage and Harris (1982), studying space use on 4.5 ha of University of Kansas campus, found home range mean group distance of both gray and fox squirrels to be 100 m, regardless of sex. Baumgartner (1938) reported fox squirrel daily movement to be within the

boundaries of the woodlot.

Other studies document home ranges expanding with increased patch size (Nixon 1968). An extensive literature search by Weigl et al. (1992) found home ranges of southeastern fox squirrels (17-40 ha) to be considerably larger than that of western fox squirrels (0.8-7.0 ha) and that home ranges varied with sex, season, food availability, and population densities. Densities of fox squirrels ranged from 1.18 per 0.4 ha maximum in the winter, in Kansas (Packard 1956), to 1.66 per 0.4 ha in Illinois (Brown and Yeager 1945), and 0.18 fox squirrel per 0.4 ha in winter, in Michigan (Allen 1942). Nixon (1968) reported that home ranges varied between woodlots (0.4-2.0 ha) and continuous tracts of forest (4-6 ha), with squirrel populations of 2-3 per 0.4 ha in forests, and 2-4 per 0.4 ha in woodlots due to crop residue supplementing the annual hard mast crop. Nearly two decades later, Nixon and Hansen (1987) reported 1-2 fox squirrels per 0.4 ha in Illinois. Nixon et al. (1980) suggested that 15-20 oaks and hickory per ha provided sufficient mast crop to support 2-3 squirrels per ha.

Nixon et al. (1985) stated that “amount of winter-storable food available is key to sustain squirrel abundance”. The “fall shuffle”, an annual dispersal that coincides with mast crop production, has been reported by both hunters and investigators (Allen 1942; Baumgartner 1943; Brown and Yeager 1945; Christisen 1970; Lurz et al. 2000), and was thought, by some, to be the result of intra specific intolerance (Baumgartner 1943; Brown and Yeager 1945; Packard 1956). Invariably, fluctuations in food supply influenced mortality rate because unlike the “patch resident” gray squirrel, “patch transient” fox squirrels traveled to find available foods (Steele and Weigl 1992). Allen (1942) once

followed a fox squirrel that had carried an ear of corn 0.5 km.

The overwhelming majority of studies of fox squirrel habitat use occurred in regions of extensive mast crop production, only a few resembled the situation of my study area, in that most habitat patches lack hard mast producing trees. Kline (1964), in Iowa, reported that only 7.3% of Iowa was wooded, and the mast crop influence was mitigated by availability of agricultural crops, particularly corn. Fall movements still occurred, apparently either from food shortages or because dispersal was natural. Interestingly, Kline (1964) observed that populations were stable in agricultural areas, while populations fluctuated in wooded areas. In the Black Prairie region of Illinois, an Osage orange-corn-soybean combination was the most common fox squirrel habitat, supplemented in some cases by walnut, oaks, and maples. In farm habitats where mast was absent, Osage orange ranked next to corn for preferred foods (Brown and Yeager 1945).

Mast crops were not widely available in wooded areas of Kansas, so understandably fox squirrels must have consumed a wide variety of foods in order to occupy its current range in Kansas. While corn was widely available in other regions of the Midwest, and certainly is the row crop favored by fox squirrels, only five fields (4.1%) of the tilled land within my sites were planted to corn in 1999. Fox squirrels might be using the plethora of other food resources listed in the literature (see Introduction). In eastern Kansas, Osage orange is a staple food of fox squirrels in winter, as well as bark and seeds of elm, dogwood, ash, sumac (*Rhus* spp.), Kentucky coffee tree and honey locust seeds, and grain. In western Kansas, winter foods include corn, wheat,

cottonwood bark, seeds of Osage orange, ash, and catalpa (*Catalpa speciosa*), and red cedar (*Juniperus virginiana*) berries (Packard 1956). Also, Bugbee and Riegal (1945) reported fruits of Russian olive (*Elaeagnus angustifolia*) being consumed in winter.

Seng and Wiggers (1991) suggested that hunting pressure might determine distribution of fox squirrels. I doubt this was the case within my study area, as most landowners that I spoke with were not squirrel hunters, nor are squirrels considered a significant game species in Kansas (R. Applegate, KDWP, pers. comm.). Brown and Yeager (1945) reported predation loss to be insignificant in Illinois and I suggest it might also be the case in my study. However, the presence of a coyote (*Canis latrans*) or bobcat (*Lynx rufus*) den, or preferred hawk or owl perch might well explain lack of occupancy of a particular habitat patch, despite the otherwise suitable condition of the patch. Allen (1942) suggested that automobiles might cause more deaths than predators (humans included). Despite a gravel road bordering nearly every section of my study area, traffic was light (relative to a residential highway), and I never saw a road killed fox squirrel. However, domestic cats (*Felis silvestris*) and dogs (*Canis lupus*) commonly were observed.

Presence of grapevines (*Vitis* spp.) increases the likelihood of a tree being occupied by a leaf nest (Sanderson et al. 1980). In Illinois, 35-85% of leaf nests were anchored by grapevines when less than 24% trees supported grapevines (Nixon and Hansen 1987). This might be an excellent explanatory variable in areas supporting many grapevines, but my study area had very few. Packard (1956) reported that cattle grazing, by reducing food supply, decreased squirrel numbers. I expected that if that were the case

at my sites, it would have been reflected in the % Shrub/Grass cover variable, as an estimated 30% of the land adjacent to and within the habitat patches were grazed.

Intuitively, I would have expected cattle grazing to enhance patch suitability, since fox squirrels prefer less than 30% understory growth (Allen 1982).

Improving the predictive power of my models might have been accomplished by increasing sample size, investigating a wider range of patch sizes, or measuring different/additional variables. Upon improving its predictive power, the models should then be applied to various other study areas within the state to validate and confirm its usefulness. Had my study area included a series of patches in the range of 3-9 ha, or if it had fewer wooded fencerows, perhaps those patches less than 2 ha would not have been occupied by leaf nests. Based on personal observation, I suggest that Osage orange is the critical food item that influences overwintering fox squirrel populations in Kansas where hard mast producing tree species are not locally abundant. In addition to honey locust being a high-energy food source, the thorns provide an excellent place of shelter. While searching for leaf nests at Lebo, I observed at least three (possibly six) fox squirrels using honey locust trees in a 4.7 ha patch containing 19 leaf nests. At first glance, one would wonder how any animal could traverse such a dense maze of thorns, but after seeing two fox squirrels exit the same thorn built nest and several other fox squirrels escaping into honey locust trees, it is possible that this species of tree might be selected by fox squirrels to avoid predation. I could not find a similar observation in the literature. Variables that I recommend including in further regression analysis or an attempt to modify the HSI model are distance to and abundance of Osage orange, and presence of honey locust.

Tischendorf and Fahrig (2000) pointed out that landscape connectivity should not be measured solely from landscape structure, e.g. number of corridors. Connectivity must be defined by the degree to which the landscape facilitates or impedes movement of an animal among resource patches (Taylor et al. 1993). Therefore, future research into habitat use by fox squirrels in Kansas should investigate home range composition, dispersal ability, and population densities to allow better management of exploited populations in fragmented habitats.

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Appendix I. A SAS program generated by converting Allen's (1982) Habitat Suitability Index (HSI) model to mathematical equations to simplify the procedure of generating an HSI value for each habitat patch.

Data HSI;

Input Woodlot Nest Mast Distanc;

If Mast < 40 Then V1 = Mast / 40;

 Else If Mast >= 40 and Mast <= 60 Then V1 = 1;

 Else V1 = (-4*Mast + 640) / 400;

If Distanc <= 200 Then V2 = 1;

 Else If Distanc > 200 and Distanc <= 600 Then V2 = (5800 - 9*Distanc) / 4000;

 Else V2 = .1;

HSIF = (3*V1+V2) / 4;

Input Woodlot Nest DBH Tree Shrub;

If DBH < 21.2 Then V3 = 0;

 Else If DBH >= 21.2 and DBH <= 37.5 Then V3 = (10*DBH - 212) / 163;

 Else V3 = 1;

If Tree <= 20 Then V4 = Tree / 20;

 Else If Tree > 20 and Tree <= 70 Then V4 = 1;

 Else V4 = (140 - Tree) / 80;

If Shrub <= 30 Then V5 = 1;

 Else If Shrub > 30 and Shrub <= 75 Then V5 = (345 - 4*Shrub) / 225;

 Else V5 = (100 - Shrub) / 125;

HSIC = (V3 * V4 * V5) ** (1/3);

Cards;

Proc Print; var Woodlot Nest Mast Distanc V1 V2 HSIF;

Proc Print; var Woodlot Nest DBH Tree Shrub V3 V4 V5 HSIC;

Proc Plot; Plot Nest*HSIF;

Proc Plot; Plot Nest*HSIC;

Run;

Appendix II. Summary of nest data, 15 explanatory variables (13 of the variables were used to generate predictive models), and HSI values for 58 and 72 habitat patches on Troublesome and Lebo creeks, respectively. Explanatory variables include: habitat type (Patch Type); area; perimeter; distance from each patch to core (DistCore), to nearest water source (DistWater), to nearest grain (DistGrain), to nearest patch, if any, serving as a stepstone to core (DistStepstone), and to nearest occupied patch (DistOccupied); Grain Type; # of corridors; # of continuous connections to core (# Connections); % Shrub/Grass cover (% Shrub/Grass); % Canopy closure (% Canopy); and Tree community similarity (TreeCommunity). Available grain types include: alfalfa (a), corn (c), fallow (f), milo (m), soybeans (s), wheat-fallow (w-f), and feedlot (fl). Habitat types include: homestead (hs), hedgerow (hr), fencerow (fr), and woodlot (w).

Troublesome Creek

Patch #	# Nests	Patch Type	Area (ha)	Perimeter (m ²)	DistWater (m)	DistGrain (m)	Grain Type	DistCore (m)	DistStepstone (m)	DistOccupied (m)	# Corridors	# Connections	DBH (cm)	% Shrub/grass	% Canopy	TreeCommunity	HSI Cover Value	HSI Food Value
1	0	w	0.07	139	90	156	m	348	43	348	2	1	75	13	90	-0.03	0.85	0.25
2	0	w	0.21	246	63	210	s	190	.	190	1	1	76	53	97	0.74	0.68	0.24
3	1	w	0.03	166	0	0	s	995	777	995	0	0	64	12	70	-0.24	0.96	0.25
4	0	fr	0.03	104	298	0	s	833	670	440	0	0	106	0	72	-0.8	0.95	0.25
5	0	w	0.61	470	0	0	s	609	.	609	0	0	41	86	78	0.17	0.44	0.25
6	0	w	0.06	166	0	164	s	1402	653	729	0	0	46	0	41	0.01	1.00	0.25
7	0	w	0.03	110	0	304	s	1380	511	707	0	0	35	0	78	-0	0.87	0.19
8	0	hs	0.06	168	171	0	s	942	153	706	0	0	53	14	85	-0.5	0.88	0.25
9	0	fr	0.05	147	674	0	s/a	1174	7	477	1	0	45	33	95	-0.6	0.81	0.25
10	0	fr	0.04	122	672	0	s/a	1151	106	481	1	0	33	20	96	-0.4	0.74	0.25
11	0	w	0.02	85	351	0	s/m	1684	50	84	2	0	43	29	77	-0.4	0.92	0.25
12	0	w	0.01	63	390	0	s/m	1645	173	91	2	0	42	45	92	-0.4	0.76	0.25
13	1	w	0.08	130	450	0	m	1578	71	1432	3	0	51	73	95	-0.5	0.52	0.25
14	0	w	0.21	251	563	0	m	1440	107	71	2	0	57	62	90	-0.5	0.64	0.25
15	0	w	0.02	68	826	40	s	1290	349	335	2	0	70	43	85	-0.4	0.81	0.25
16	0	w	0.04	95	728	108	s	1370	75	233	3	0	42	48	80	-0.3	0.80	0.25
17	0	w	0.19	308	758	21	s	1402	103	288	1	0	43	0	91	0.73	0.85	0.25
18	0	w	0.04	134	692	86	s	1466	31	219	2	0	61	40	72	-0.2	0.89	0.25
19	0	w	0.02	86	267	0	s	1380	388	845	0	0	69	28	78	-0.5	0.92	0.25
20	0	w	0.77	675	79	0	s	677	138	138	2	2	41	16	60	0.11	1.00	0.25
21	10	w	5.08	1378	27	0	s	40	.	40	3	1	46	15	64	-0.1	1.00	0.25
22	0	hr	0.12	146	464	0	s	586	37	37	2	2	29	38	84	0.44	0.67	0.25
23	1	hr	0.22	342	502	0	s	629	37	328	2	2	53	40	97	0.5	0.76	0.25
24	0	fr	0.01	56	389	0	s	486	185	160	2	2	28	3	80	0.09	0.70	0.25

Patch #	# Nests	Patch Type	Area (ha)	Perimeter (m ²)	DistWater (m)	DistGrain (m)	Grain Type	DistCore (m)	DistStepstone (m)	DistOccupied (m)	# Corridors	# Connections	DBH (cm)	% Shrub/grass	% Canopy	TreeCommunity	HSI Cover Value	HSI Food Value
25	0	fr	0.03	78	246	0	s	308	75	308	3	2	65	68	83	-0.3	0.62	0.25
26	0	w	0.01	45	132	0	s	145	.	145	2	2	58	50	52	-0.5	0.86	0.25
27	0	w	0.08	147	0	0	f	296	103	243	1	1	42	33	65	-0.1	0.98	0.25
28	0	w	0.41	300	15	48	f	236	136	136	3	1	38	26	70	0.2	0.96	0.25
29	0	w	0.09	150	141	16	m	441	117	333	2	1	38	13	84	0.23	0.89	0.25
30	0	w	0.46	573	0	0	m	638	160	537	1	1	41	65	96	0.13	0.59	0.25
31	4	w	1.53	539	110	0	m/w-f	45	.	45	2	1	47	70	92	-0.2	0.56	0.25
32	4	w	2.14	988	91	0	s	45	.	45	1	1	59	49	86	0.57	0.77	0.25
33	0	hr	0.36	521	59	65	s	45	.	45	1	1	74	0	87	1.2	0.87	0.25
34	4	w	0.41	283	131	0	m	539	299	299	0	0	51	70	96	0.12	0.54	0.25
35	0	fr	0.09	153	667	0	s/m	1039	206	713	0	0	58	18	92	0.06	0.84	0.25
36	0	fr	0.04	101	745	0	s/m/w	900	754	754	0	0	17	53	94	0.48	0.00	0.25
37	0	hs	0.56	552	136	0	fl	1190	589	589	2	0	42	19	76	-0.1	0.93	0.25
38	0	w	0.77	924	0	32	s	1348	259	755	1	0	66	14	47	0.62	1.00	0.25
39	0	w	0.36	272	240	35	s	1125	220	1125	0	0	31	26	72	-0.2	0.82	0.25
40	0	hs	0.68	485	160	0	w-f	583	454	454	3	1	44	46	51	-0.7	0.90	0.25
41	0	w	1.73	1196	0	79	s	39	.	39	2	1	51	31	85	0.05	0.88	0.37
42	1	w	0.93	462	115	158	s	169	31	169	2	1	65	77	85	0.25	0.50	0.25
43	0	w	0.10	149	38	96	s	93	27	31	3	1	41	40	83	0.31	0.84	0.42
44	0	w	0.18	190	0	142	s	119	.	96	1	1	53	28	91	-0.1	0.85	0.25
45	0	w	0.04	143	0	31	s	33	.	33	2	1	59	50	72	1.05	0.82	0.95
46	0	w	0.08	145	80	30	s	20	.	25	1	1	45	61	90	0.35	0.65	1.00
47	0	w	0.04	124	194	20	s	10	.	7	1	1	36	73	86	1.11	0.52	0.83
48	13	w	1.08	509	74	279	s	81	.	81	2	1	43	43	96	0.22	0.75	0.67
49	0	fr	0.08	156	44	301	s	107	.	107	2	2	53	5	91	0.39	0.85	0.19
50	0	w	1.19	745	12	127	s	711	707	711	0	0	66	28	88	-0.7	0.87	0.25
51	0	w	0.12	170	46	74	s	1505	23	39	2	0	64	28	91	0.33	0.85	0.25
52	0	w	0.31	275	107	112	s	1394	23	879	3	0	76	48	97	0.01	0.72	0.25
53	0	w	0.78	545	145	0	w-f	1375	124	953	2	0	52	67	96	0.28	0.57	0.25
54	0	fr	0.20	199	416	0	m/w-f	1080	404	1080	2	0	76	42	93	-0.1	0.78	0.25
55	0	fr	0.11	153	457	0	s/w-f	1318	150	1291	3	0	42	53	94	-0.3	0.70	0.25
56	0	fr	0.06	141	561	0	s/w-f	1477	124	1477	1	0	67	0	94	-0.8	0.83	0.25
57	0	w	0.50	433	0	0	f/s	1037	271	1037	0	0	45	57	89	-0.3	0.69	0.25
58	0	w	0.23	221	305	0	s	1410	490	1410	1	0	28	48	70	-0.6	0.69	0.25

Lebo Creek

Patch #	# Nests	Patch Type	Area (ha)	Perimeter (m ²)	DistWater (m)	DistGrain (m)	Grain Type	DistCore (m)	DistStepstone (m)	DistOccupied (m)	# Corridors	# Connections	DBH (cm)	% Shrub/grass	% Canopy	TreeCommunity	HSI Cover Value	HSI Food Value
1	0	fr	0.04	104	196	0	s	1538	690	824	0	0	37	15	79	0.28	0.90	0.25
2	0	w	0.03	61	30	75	s	290	12	12	3	2	38	0	96	0.66	0.82	0.25
3	1	hs	0.03	72	0	0	s	480	56	5	4	2	58	0	90	-0.3	0.85	0.25
4	19	w	4.73	1748	0	0	s/m	606	5	5	2	4	41	25	62	0.4	1.00	0.25
5	0	hr	0.19	304	0	0	s	1052	428	360	0	0	50	10	82	0.48	0.90	0.25
6	1	w	0.14	430	0	0	s	1439	390	705	0	0	49	24	85	0.44	0.88	0.25
7	0	hr	0.23	399	46	7	m	7	.	7	5	2	27	30	82	0.53	0.66	0.25
8	1	w	0.03	86	76	0	m	241	185	241	3	2	66	18	84	0.3	0.89	0.25
9	0	w	0.01	63	94	12	s	104	.	104	5	3	44	0	67	0.66	1.00	0.25
10	0	w	0.02	94	111	12	s	133	11	133	4	2	40	0	86	0.7	0.88	0.25
11	0	w	0.01	59	99	41	s	135	21	128	3	2	26	5	87	0.3	0.59	0.25
12	0	w	0.01	44	90	41	s	166	23	101	3	2	28	9	72	0.24	0.73	0.25
13	1	W	0.02	85	31	100	S	271	101	231	3	2	35	28	88	0.3	0.81	0.25
13	1	w	0.02	85	31	100	s	271	101	231	3	2	35	28	88	0.3	0.81	0.25
14	1	w	0.05	113	184	0	s	453	46	170	2	4	49	19	95	0.34	0.83	0.25
15	0	w	0.02	87	64	115	s	338	50	50	3	2	46	3	92	0.57	0.84	0.25
16	0	w	0.01	65	176	46	s	475	188	46	2	2	46	69	85	0.41	0.59	0.25
17	4	hs	0.30	547	147	0	s	710	105	108	3	8	65	17	90	0.32	0.85	0.25
18	4	w	0.69	633	356	0	s	630	210	175	3	8	44	21	81	0.39	0.90	0.25
19	0	w	0.08	159	186	0	s	430	42	53	1	3	47	4	79	0.41	0.91	0.25
20	8	w	0.41	425	268	0	s	318	190	167	3	3	43	33	88	0.38	0.85	0.25
21	0	w	0.21	181	170	0	s	73	66	66	4	4	64	24	89	0.48	0.86	1.00
22	1	fr	0.05	114	813	0	s	1321	198	198	3	3	38	55	90	0.36	0.70	0.25
23	1	fr	0.03	72	712	0	s	1155	3	3	3	3	135	50	100	0.65	0.69	0.25
24	50	w	12.86	8580	0	0	s/w-f	938	108	3	4	3	58	47	85	0.53	0.78	0.59
25	0	hr	0.32	526	474	0	s	798	386	162	3	3	79	44	90	0.45	0.78	0.25
26	0	fr	0.34	437	262	0	s	754	356	356	1	1	50	20	99	0.51	0.80	0.25
27	5	fr	0.57	845	185	0	s/m	105	0	105	2	1	59	31	93	0.51	0.83	0.25
28	0	w	0.03	76	237	0	s	108	26	26	2	1	30	18	92	0.77	0.70	0.25
29	1	hs	0.14	247	435	10	s	1057	621	1057	0	0	77	0	89	0.09	0.86	0.25
30	0	w	0.06	147	38	0	m	1155	51	630	0	0	48	87	73	0.76	0.45	0.25
31	23	w	2.49	705	150	0	c	24	.	26	3	1	50	43	86	0.47	0.81	1.00
32	1	hr	0.20	519	405	0	s/c/m	258	55	55	3	1	38	29	93	0.5	0.84	0.25
33	0	w	0.22	236	0	0	s	1305	558	357	2	1	25	35	69	0.44	0.65	0.25
34	0	hr	0.18	268	247	0	s	1467	222	190	2	1	46	33	76	0.51	0.91	0.25
35	20	hr	11.03	5967	0	0	s/c/m	229	55	55	3	1	52	36	79	0.34	0.88	0.28
36	0	hs	0.03	106	164	0	m	204	0	204	1	0	41	26	71	0.28	0.95	0.25
37	0	w	0.01	41	383	0	s	1632	561	657	3	1	35	18	91	0.35	0.80	0.25
38	0	w	0.04	78	460	0	s	1559	10	618	3	1	49	9	92	0.46	0.85	0.25
39	0	fr	0.07	194	286	0	m	924	258	515	3	1	45	58	97	0.31	0.65	0.25
40	0	fr	0.08	199	146	0	m	865	56	505	3	1	45	51	82	0.43	0.77	0.25
41	0	fr	0.04	144	119	0	m	1128	159	220	2	1	27	65	100	0.35	0.43	0.25

Patch #	# Nests	Patch Type	Area (ha)	Perimeter (m ²)	DistWater (m)	DistGrain (m)	Grain Type	DistCore (m)	DistStepstone (m)	DistOccupied (m)	# Corridors	# Connections	DBH (cm)	% Shrub/grass	% Canopy	TreeCommunity	HSI Cover Value	HSI Food Value
42	0	w	0.30	299	17	45	m	1160	221	705	0	0	49	1	84	0.23	0.89	0.25
43	0	hs	0.03	108	157	9	m	828	365	626	0	0	69	0	92	-28	0.85	0.25
44	0	w	0.01	93	0	0	m	779	35	425	1	0	80	18	48	0.28	1.00	0.25
45	0	w	0.08	115	8	529	m	872	3	767	2	2	154	0	91	0.65	0.85	0.06
46	0	w	0.03	93	17	505	s/m	849	643	748	2	2	97	0	89	0.67	0.86	0.08
47	0	fr	0.29	390	0	0	m	615	91	236	2	0	55	32	39	0.31	0.99	0.25
48	0	fr	0.11	199	116	0	m	486	131	131	2	0	78	14	92	0.38	0.84	0.41
49	1	w	0.26	259	102	0	s	318	100	319	2	0	70	56	69	0.42	0.81	0.25
50	0	w	0.23	365	0	0	s	342	237	100	2	0	42	61	66	0.41	0.76	0.25
51	0	w	0.05	121	39	0	s	436	36	120	1	0	58	49	90	0.39	0.75	0.25
52	0	w	0.33	72	265	0	s/m	261	51	222	2	2	64	60	94	0.47	0.65	0.25
53	0	w	0.02	67	328	0	m	194	54	153	3	2	57	28	69	0.61	1.00	0.25
54	0	w	0.03	75	299	8	m	143	52	101	3	2	68	63	95	0.58	0.62	0.25
55	0	w	0.02	62	256	0	m	36	10	10	3	2	79	58	90	0.26	0.68	0.25
56	1	w	0.11	218	197	30	m	20	.	20	3	2	60	39	85	0.36	0.83	0.25
57	1	w	0.08	161	166	0	m	16	.	16	3	2	33	80	88	0.56	0.42	0.25
58	0	w	0.79	368	65	0	m	27	.	27	3	1	41	19	72	0.37	0.95	0.25
59	3	w	0.14	272	51	240	s	28	.	28	1	1	104	33	94	0.68	0.82	0.25
60	0	fr	0.27	550	0	0	fl	710	673	673	3	1	32	0	92	0.08	0.74	0.25
61	4	w	0.60	310	94	60	fl/m	59	.	59	3	1	38	3	47	0.27	1.00	0.25
62	12	w	1.39	695	132	244	s	244	106	106	1	1	69	10	71	0.43	0.95	0.23
63	0	fr	0.37	380	90	0	s	10	.	10	3	1	31	47	89	0.33	0.66	0.25
64	1	fr	0.20	220	36	0	s	326	176	245	2	2	31	15	91	0.25	0.73	0.25
65	0	w	0.59	373	120	0	s	296	183	275	2	1	33	17	94	0.33	0.74	0.25
66	0	fr	0.06	122	24	0	s	484	82	190	4	2	26	35	82	0.33	0.62	0.25
67	2	hs	0.07	188	93	0	s	228	190	385	2	2	78	0	91	0.22	0.85	0.25
68	0	w	0.34	471	0	0	s	829	554	731	0	0	57	43	80	0.3	0.83	0.38
69	0	w	0.11	164	163	0	s	269	91	170	2	2	40	34	78	0.14	0.90	0.25
70	0	w	0.27	217	22	88	s	140	21	81	3	2	94	11	72	0.17	0.95	0.25
71	0	w	0.41	323	0	107	s	0	.	0	3	1	81	52	55	0.19	0.85	0.25
72	5	w	0.79	424	0	139	s	0	.	0	2	1	80	39	54	0.11	0.94	0.60

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Jacqueline A. DeSanty
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05/11/01
Date

Factors affecting habitat use by the fox squirrel (*Sciurus niger rufiventer*) in fragmented
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Title of Thesis

Dorey Logan
Signature of Graduate Office Staff

May 11, 2001
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