HABITAT AFFILIATIONS OF SYMPATRIC CARNIVORES IN SOUTHERN ILLINOIS

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This study incorporated the Penrose distance statistic, multivariate statistics, carnivore sighting data, and land cover data within a GIS to create habitat models for sympatric red foxes, coyotes, and bobcats in southern Illinois. Habitat variables were quantified for 1-km² buffered areas around carnivore sighting locations. Only one variable differed between coyote-red fox and coyote-bobcat pairings, demonstrating significant overlap in these two species-groups. However, five variables differed between red foxes and bobcats, indicating considerable differences in habitat affiliation between these species. Model validation by independent sighting locations determined model fit was good, with 64% and 65% of the validation points for red foxes and bobcats, respectively, falling within the top 50% of Penrose distance values. Red foxes were affiliated with mixtures of agriculture and grassland cover, while bobcats were associated with a combination of grassland, wetland, and forest cover. This study provides insight into habitat partitioning and overlap among sympatric carnivores.

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CHAPTER 1

INTRODUCTION

Red foxes (*Vulpes vulpes*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*) are often described as sympatric carnivores, that is, they are typically found in similar geographic areas and thus overlap in their distribution. They are three of the larger carnivores native to Illinois, and their ranges throughout the United States are widely distributed (Cypher 2003; Bekoff and Gese 2003; Anderson and Lovallo 2003). There is typically some overlap in home ranges and habitat between conspecifics and other sympatric carnivores (Grosselink et al. 2003; Chamberlain and Leopold 2005). However, continued reduction in wildlife habitat may force greater overlap which could cause greater resource partitioning and competition among species, or cause individuals to seek resources outside of their normal habitats (Fedriani et al. 2000).

Red foxes, coyotes, and bobcats are important renewable resources to maintain in Illinois for ecological, economic, and recreational reasons. The foremost reason is all three species are an integral part of the food web. Healthy populations of secondary and tertiary consumers are vital in maintaining the balance of other species in the ecosystem. For example, the overabundance of white-tailed deer (*Odocoileus virginianus*) is a result in large part to the lack of large natural predators. Secondly, current state hunting and trapping regulations allow annual harvesting of red foxes and coyotes. Thus, they provide revenue to the state wildlife agency in the form of license fees, and the sale of pelts provides income to fur takers and sellers (Bluett 2004). The last reason for maintaining these species is there is an aesthetic value placed on them by those who enjoy wildlife viewing. Mankin et al. (1999) noted a high percentage of survey respondents indicated that wildlife was important to them and wildlife and conservation education in the schools also was important.

Estimating wildlife population size, distribution, home range size, habitat use and other aspects of a species' natural history is not only difficult due to the time and funding involved, but also requires costly equipment necessary to conduct the field work. Archery Deer Hunter Surveys (ADHS) (Bluett 2004) and Fur Harvest Surveys (FHS) (Bluett 2004) are methods biologists use in Illinois to estimate the status of game species in regards to distribution and abundance, however they are not comprehensive. These surveys are conducted at a county level without analysis of species-habitat relationships. According to recent Illinois FHS data, the number of red fox pelts sold during 2003–04 were up from 2002–03 (Table 1.1). However, Statewide ADHS data from 1992–2003 shows a declining trend in red fox sightings, indicating the red fox population in Illinois may also be declining with the current harvesting practices (Table 1.2). Harvesting may place additional pressure on populations which may already be taxed by extrinsic factors. For example, bobcats historically have been harvested in Illinois; however, a decline in their population resulted in their exclusion from consumptive wildlife recreation to allow their population to increase. Bobcats were de-listed from Illinois' threatened species list in 1999, though they are still listed as a non-game species. Habitat modeling has shown to be an accurate method of determining wildlife-habitat relationships (Edwards et al. 1995), and has been instrumental in providing biologists science-based information to assist in making land and species management decisions (Woolf et al. 2002).

Table 1.1. Comparative fur harvest data for Illinois, 2002–03 vs. 2003–04 (Bluett 2004)

Species	Number of pelts sold [a]		Change in sales from 2002-03 [b]		Average price per pelt (dollars)		Total value to fur-takers (dollars)		Change in value from 2002-03 (dollars)	
	2002-03	2003-04			2002-03	2003-04	2002-03	2003-04		
Muskrat	34,860	21,555	-13,305	(-38.2)	2.55	2.60	88,893.00	56,043.00	-32,850.00	(-36.9)
Mink	2,911	2,552	-359	(-12.3)	7.70	8.85	22,414.70	22,585.20	-170.50	(-0.8)
Raccoon	129,101	153,640	+24,539	(+19.0)	7.20	8.90	929,527.20	1,367,396.00	+437,868.80	(+47.1)
Opossum	5,849	7,340	+1,491	(+25.5)	1.30	1.50	7,603.70	11,010.00	+3,406.30	(+44.8)
Red Fox	1,270	1,330	+60	(+4.7)	19.45	18.65	24,701.50	24,804.50	+103.00	(+0.4)
Gray Fox	101	114	+13	(+12.9)	12.75	16.25	1,287.75	1,852.50	+564.75	(+43.8)
Beaver	4,026	4,947	+921	(+22.9)	8.15	10.05	32,811.90	49,717.35	+16,905.45	(+51.5)
Striped Skunk	547	636	+89	(+16.2)	2.80	4.35	1,531.60	2,766.00	+1,235.00	(+80.6)
Weasel	11	25	+14	(+127.3)	0.50	0.60	5.50	15.00	+9.50	(+172.70)
Coyote	5,460	8,268	+2,808	(+51.4)	11.75	13.35	64,155.00	110,377.80	+46,222.80	(+72.0)
Badger	25	36	+11	(+44.0)	10.10	13.15	252.50	473.40	+220.90	(+87.5)
Total/mean	184,161	200,443	+16,282	(+8.8)	6.35	8.20	1,173,184.35	1,647,041.35	+473,857.00	(+40.4)

[a] Includes correction for non-response and allowances for out-of-state pelt sales as estimated by the Illinois Furbearer Trapping Survey, 2002-03 (Wildlife Harvest and Hunter Opinion Surveys, W-112-R).

[b] Numbers in parentheses indicate percentage change between years.

Table 1.2. Trends in statewide Archery Deer Hunter Survey sighting index in Illinois, 1992–2003, using hunter-location method of analysis (Bluett 2004)

Year	Species							
	Bobcat	Coyote	Deer	Gray Fox	Raccoon	Red Fox	Squirrel	Turkey
1992 (1,239)[a]	0.53 (0.29)[b]	27.09 (3.16)	655.29 (33.09)	2.50 (1.11)	30.14 (3.47)	9.25 (2.00)	972.66 (34.53)	93.41 (20.25)
1993 (2,877)	0.65 (0.27)	29.68 (2.82)	611.17 (17.21)	1.90 (0.41)	49.35 (3.19)	8.06 (0.99)	1017.30 (24.83)	123.85 (16.17)
1994 (1,814)	0.40 (0.17)	28.44 (3.34)	586.54 (19.69)	1.68 (0.51)	46.74 (3.61)	5.67 (0.92)	1089.03 (32.35)	146.25 (20.15)
1995 (2,278)	0.81 (0.28)	30.57 (2.59)	696.88 (21.99)	1.61 (0.49)	52.53 (3.66)	6.64 (0.95)	995.29 (26.28)	138.17 (16.13)
1996 (1,458)	0.80 (0.33)	27.50 (3.20)	662.87 (27.05)	1.18 (0.51)	45.73 (3.98)	4.68 (0.89)	938.52 (31.63)	144.45 (19.59)
1997 (1,411)	1.34 (0.77)	26.48 (2.93)	661.98 (27.14)	0.64 (0.33)	47.16 (4.68)	5.45 (0.96)	981.15 (33.60)	139.24 (19.59)
1998 (2,052)	1.10 (0.38)	30.82 (2.82)	736.18 (23.46)	0.80 (0.28)	49.18 (3.54)	6.02 (1.22)	928.99 (28.31)	201.51 (20.92)
1999 (1,931)	1.37 (0.44)	32.26 (2.75)	729.16 (23.59)	1.39 (0.99)	63.02 (4.53)	3.51 (0.65)	988.98 (28.81)	241.48 (23.26)
2000 (1,854)	1.10 (0.40)	30.56 (2.49)	853.55 (26.68)	0.68 (0.31)	65.90 (5.36)	4.11 (0.81)	1087.00 (32.30)	272.55 (34.52)
2001 (1,366)	1.57 (0.83)	32.35 (3.35)	918.72 (33.57)	0.76 (0.50)	66.64 (5.89)	4.42 (1.02)	1266.34 (40.58)	311.16 (35.32)
2002 (1,780)	2.00 (0.66)	34.47 (3.11)	995.25 (32.67)	0.60 (0.26)	55.07 (3.96)	3.74 (0.65)	1081.09 (35.79)	348.07 (31.68)
2003 (1,569)	2.10 (0.59)	29.75 (2.85)	1033.49 (34.47)	0.81 (0.36)	65.72 (5.05)	3.53 (0.76)	1177.41 (34.69)	308.02 (28.65)

[a] Number of observers in parentheses following year.

[b] 95% confidence limit is in parentheses following the number of sightings per 1,000 hours.

Red foxes, coyotes, and bobcats have been selected for this habitat modeling study for two reasons. First, habitat models are currently unavailable for red foxes and coyotes in Illinois. Coyotes are probably the most abundant of the three species in the state, therefore determining their habitat use in relation to other native carnivores through modeling could assist wildlife managers in managing coyote populations if research suggests they are negatively affecting other species' populations through depressive competition (Fedriani et al. 2000). Red foxes are considered to be a fairly common species, though recent ADHS data shows otherwise for Illinois (Bluett 2004). Although habitat models have been created for the bobcat within the past few years (Nielsen and Woolf 2002; Woolf et al. 2002), a current regional model may be used to assess their status after being de-listed from the threatened species list. Second, all three carnivores are competitors, but red foxes in particular are generally out-competed by coyotes which can greatly affect their abundance, and spatial and temporal partitioning of resources (Cypher 2003). Bobcats share similar resources with the coyote, but may be able to avoid some competition through temporal partitioning (Fedriani et al. 2000). Knowledge of carnivore-habitat relationships for all three species and how these habitats are distributed may help determine how the region could be managed to promote healthy populations.

With the exception of bobcats, there have been only a few recently published studies of red foxes and coyotes in Illinois (Gosselink et al. 2003; Lavin et al. 2003; Nelson and Lloyd 2005). Thus, this study may contribute additional information regarding habitat affiliations and how they may affect interactions among these species. Sighting data from this study may also indicate the general status of these species in the region. Single-species modeling studies have been conducted for a variety of wildlife, however to my knowledge there have not been any published studies using a multi-species approach for the red fox, coyote and bobcat. Thus, the modeling technique used in this study may pave the way for other researchers to conduct multi-species studies for these or other species. Remote sensing and GIS technologies have become widely used by biologists in creating models showing the relationships among wildlife and habitat types (Stoms et al. 1993; Quinn 1995; Knick and Dyer 1997; Erickson et al. 1998; Carroll et al. 1999; Hargis et al. 1999; Reunanen et al. 2000). The purpose of this study is to create regional habitat models for the red fox, coyote, and bobcat that depict habitat affiliations and their potential distributions to assist biologists in making management decisions.

Red foxes, coyotes, and bobcats often utilize similar resources which can negatively affect less-dominant species if present in the same geographic area. The following questions were established to address habitat relationships among these species in this study, and to provide insight into how those relationships might affect their local populations:

- Which habitat affiliations are associated with red foxes, coyotes and bobcats?
- Are there significant differences in habitat affiliations among the species?
- What are the habitat distributions for each species, and how much overlap in habitat affiliation occurs among sympatric carnivores?

CHAPTER 2

LITERATURE REVIEW

Wildlife abundance is a good indicator of the general health of the environment. There have been several cases in which wildlife populations have declined, particularly due to the effects of contaminants, habitat loss, and habitat fragmentation. A well-known example was the decline of the peregrine falcon (*Falco peregrinus*) population to endangered status in the United States. Extensive use of organochlorine pesticides, DDT in particular, from the 1940s through 1972 contaminated much of our country's soil, plants and natural water resources. As a result of the persistent chemical cycling through ecosystems, the peregrine falcon and other bird species experienced low reproductive success (Steidl et al. 1991). Studies eventually determined DDE, a metabolite of DDT, had a thinning effect on eggshells causing premature cracking during incubation (Grier 1982).

Another example of environmental effects on species is the effect of deforestation on Neotropical migrants. Neotropical migrants are small passerine birds, such as the cerulean warbler (*Dendroica cerulea*) and red-eyed vireo (*Vireo olivaceus*), that migrate to South American forests in winter, and return to North American forests in the spring for their breeding season. These birds are considered "forest interior" species because of their preference to nest within large tracts of forests. Forest reduction and fragmentation forces these migrants to nest near edges of forests where they have succumbed to nest parasitism by brown-headed cowbirds (*Molothrus ater*) (Friesen et al. 1999).

Flaspohler et al. (2001) studied the edge effects on nest success for eight common bird species in forests ranging between 15 and 40 years since their last major harvest. Their findings determined nest predation was the primary cause for nest failure in all species studied, and ground-nesting species may have lower nest success in respect to distance from forest edges, due to a wide range of predators than those nesting in canopies.

Collingham and Huntley (2000) conducted a modeling study to determine how habitat fragmentation and patch size affected migration rates by using mesounits, or blocks to represent suitable habitat, and three varying levels of distribution patterns of these blocks. Results from all nine simulated landscapes showed significant relationships between habitat availability and migration rate. They acknowledged, however, that biological and dispersal characteristics of an organism will dictate migration rates based upon their interaction with the environment.

Habitat loss and fragmentation can also have a negative impact on mammal populations by limiting food resources, affecting normal home range sizes and territories of individual species, changing the dynamics of inter- and intra-species relationships, and increasing interactions and conflicts with humans. Litvaitis (1993) determined the distribution of New England cottontails had decreased 40% in New Hampshire since 1950, which he attributed to the loss of early successional forests with thick understory. A resulting trend showed fewer cottontail remains in bobcat carcasses. In contrast, Heske (1995) observed no edge effects in highly fragmented areas among small mammals and furbearers when comparing forest-interior habitats and forest-farm edges.

Habitat loss and fragmentation are some of the greatest factors that continue to affect wildlife populations today as urban development expands into rural landscapes. The Illinois landscape alone has changed significantly over the past two centuries. The United States General Land Office surveyed Illinois from 1807 through 1844, and estimated 38.2% of forested land cover and 61.2% prairie habitat. Today the amount of forested cover estimated in Illinois is 12% (Iverson 1991). Humans have benefited from forests as a source of timber production, fuel wood, and for recreation and scenic values. However, their sustainability and restoration are equally necessary for providing habitat to maintain biologically diverse wildlife species (Rosenblatt et al. 1999). Forested cover is an important habitat type due to its common preference among bobcats. However, other cover types such as old field and grassland habitats are also exploited and equally important to the coyote and red fox.

2.1 Species Natural History

Due to the dynamic interactions between red foxes, coyotes, and bobcats in this study, much research has been conducted on habitat use and preference, food selection, home range patterns, and the interactions among conspecifics and sympatric species. Studies have been conducted on these species in various regions, and the types of vegetation, climate, and elevation in one region may be quite different from another, thus the use of resources will also be different. Habitat use and prey items are often selected based on quality and quantity of available resources, and potential pressure from other wildlife. Species that are common in certain geographic areas do not appear to receive the same attention as those with threatened or endangered status, and may not be studied as extensively. However, several single- and multi-species studies exist on the sympatric carnivores in this study.

2.1.1 *Bobcats*

Bobcats are found in various habitats, though they prefer rough, rocky landscapes with dense cover for ambushing prey (Anderson and Lovallo 2003). Bobcats in Idaho used lower elevations with open, rocky terrain in the winter, whereas timbered areas with a variety in terrain were used in the summer (Koehler and Hornocker 1989). Similarly, Kolowski and Woolf (2002) observed higher use of rock outcroppings in the winter and less during the summer, though dense vegetation and understories were equally important for both seasons in regards to resting cover and prey abundance. In southeastern Colorado, bobcats selected rocky locations with steep slopes and little herbaceous ground cover for loafing, but loafing sites contained more vertical cover than at random locations (Anderson 1990). In north-central Montana, 89% of relocated bobcats were found in thick Douglas-fir, juniper thicket, and river bottom habitats, all of which coincided with high densities of prey (Knowles 1985). Litvaitis et al. (1986) also observed that bobcats selected between locations with thick softwood or hardwood understories, which were also based upon preference or abundance of snowshoe hares (*Lepus americanus*).

Bobcats often show differences in cover-type use by sex and seasons. Fuller et al. (1985) observed female bobcats using pine and balsam fir cover-types more, and black spruce less than males in one study area, and more lowland deciduous cover than males at another site; differences in cover-type use also occurred between sexes in summer and winter. In a Kansas prairie ecosystem, resident bobcats preferred grassland in the summer, but preferred woodlands in the winter (Kamler and Gipson 2000). Rolley and Warde (1985) determined females used deciduous forests more in the spring and summer, with grass use peaking in winter and brush use declining winter through summer. Males, on the other hand, showed deciduous forest use peaking in autumn, grass use peaking in spring, and brush use increasing from winter to spring before declining in summer.

2.1.2 *Coyotes*

Habitat use for coyotes is similar to bobcats, though they prefer more grassland to forested cover (Neale and Sacks 2001), and have shown to tolerate fragmented habitat and human activity more than bobcats (Tigas et al. 2002). Holzman et al. (1992) observed that coyotes in Georgia were non-preferential to habitat use during diurnal periods, though young pine plantations, brushy areas, and bottomland hardwood forests were used slightly more than agricultural and pasture areas; their home ranges, on the other hand, included more open areas than available at each study site. Coyotes in southeastern Colorado selected for pinyon-juniper habitat on limestone or sandstone more than expected, shrub-grassland habitat more than expected, and grassland less than expected (Gese et al. 1988). Thus, dense vegetation is important for seclusion during coyote loafing and breeding periods. Coyotes in western Montana hunted mostly in riparian and brushy wash habitats and less in grassland basins and slopes (Reichal 1991). This was attributed to a higher percentage of voles in the brushy wash and riparian areas, which were found to be the most frequent prey items of coyotes in the study area. Andelt et al. (1987) also observed changes in coyote diets based on seasonal changes in vegetation and prey abundance. In a farm region with habitat types defined as agricultural land, softwoods, hardwoods, wetlands, and developed areas, Person and Hirth (1991) observed coyotes moved more and rested less in open areas; they rested more in hardwoods. Both softwood and hardwood forests were used particularly during the breeding, gestation, and pup-rearing seasons. Coyotes did not avoid farm buildings and dwellings, but frequented those locations less during periods of pup-rearing and pup-independence.

Some studies have been conducted to determine coyote ecology between rural and urban settings. Atwood et al. (2004) studied coyotes along a suburban-to-rural gradient in west-central Indiana to investigate their activity and habitat use. Coyotes used more grassland, fence, and ditch elements within their home ranges, but also used more forested habitat than agriculture or urban areas. Home range sizes and travel distances were also greater in rural areas and smaller in urban environments. Atkinson and Shackleton (1991) studied coyotes in British Columbia which included fragmented areas of forest and undisturbed native vegetation, pasture and agricultural grasslands, croplands, urban high density housing, rural housing, recreational locations, highways, and other miscellaneous cover types. Coyotes were observed in all habitats within the study area, but primarily selected agricultural areas which included hobby farms, pastures and forests; coyotes also were most active and traveled further at night. Fragmented landscapes may also affect coyote group structure. Atwood (2006) found coyote mean group sizes in territories to be larger in aggregated patches than in those associated with dispersed patches; territories with aggregated resource patches also contained higher proportions of forest areas and less corridor habitat than in dispersed patches.

2.1.3 *Red Foxes*

Red foxes show a preference for heterogeneous and fragmented landscapes, and are also found near or within urban landscapes (Cypher 2003). Jones and Theberge (1982) studied red foxes during the summer in tundra habitat of northwest British Columbia. Individuals significantly selected for *Salix*-dominated communities, followed by grass and *Betula*-dominated communities; lichen and fen communities were used less than expected. Small mammal density was greatest in the *Salix* habitat, intermediate in the grass and *Betula* habitat, and lowest in the lichen habitat. This occurrence of habitat use relative to prey density is similar to some of the aforementioned observations in the studies of bobcats and coyotes. Cavallini and Lovari (1991) also observed that red fox habitat use was correlated to food availability and varied seasonally. Halpin and Bissonette (1988) studied the effects of snowfall on habitat use and prey availability for red foxes. Habitat use was frequent in areas where food items were prominent, hunting effort for small mammals decreased when snowfall increased, and areas with dense understory vegetation were frequently used when snow depth increased.

2.1.4 *Interactions Among Sympatric Carnivores*

Red foxes, coyotes and bobcats are all competitors, and though they often occupy similar habitats with overlapping home ranges and share food resources, they manage to co-exist through spatial, seasonal and temporal partitioning. Based on accounts from several individuals, Sargeant and Allen (1989) determined that coyotes are overtly antagonistic towards red foxes. Voigt and Earle (1983) and Dekker (1983) determined that red foxes co-existed with coyotes in most cases by avoidance. Bobcats may not avoid coyotes temporally, however seasonal avoidance may occur (Neale and Sacks 2001), and their preference for forested habitat may alleviate competition (Lovallo and Anderson 1996). Litvaitis and Harrison (1989) determined bobcat and coyote home ranges greatly overlapped, but habitat use differed for all seasons. Witmer and deCalesta (1986) also observed overlap in bobcat and coyote home ranges spatially and temporally; both species used open areas for nocturnal hunting and forested areas for diurnal resting, but coyotes preferred grassy and open clearings while bobcats preferred brushy sites. Bobcat and coyote home ranges extensively overlapped in a Mississippi study area, but did not vary seasonally (Chamberlain and Leopold 2005). In east-central Illinois, however, habitat use between red foxes and coyotes greatly overlapped during the summer, but overlapped less in the winter; there were also differences in habitat use between urban and rural red foxes (Gosseleink et al. 2003). In a mixture of habitats, coyotes preferred open habitat and used edge ecozones for hunting, while red foxes preferred brushy habitat (Theberge and Wedeles 1989). Each of these species occasionally utilizes urban areas, though they limit human avoidance primarily by their crepuscular activity (Grinder and Krausman 2001; Tigas et al. 2002).

Much of the diet for all three species consists of rodents and other small mammals. Bobcats are strictly carnivorous (Anderson and Lovallo 2003), which helps reduce competition between red foxes and coyotes. Bobcat prey selection in central Arizona consisted of 48% wood rats (*Neotoma* spp.), 38% lagomorphs, and 24% heteromyids (Jones and Smith 1979). In Maine, bobcats selected mammals as prey all seasons, while coyote prey consisted primarily of mammals in the winter and switched to an omnivorous diet in the summer (Litvaitis and Harrison 1989). In another Maine study, a small proportion of bobcat scats contained fruit, but mammals were the primary source of food; coyotes and red foxes consumed similar prey, but also switched to omnivorous diets seasonally (Dibello et al. 1990). Selecting prey by size may also allow species to co-exist (Thornton et al. 2004). Coyotes consume small to large mammals, but they are opportunistic in their diets based on the season and food availability (Bekoff and Gese 2003; Andelt et al. 1987; Reichal 1991). Atkinson and Shackleton (1991) determined the main prey items for coyotes were lagomorphs and small rodents, with seasonal use of fruits and seeds. Similar food preferences among red foxes and coyotes increases potential competition, thus foraging strategy is important for red foxes. In addition to small mammals, red foxes will occasionally consume birds, reptiles, fish and amphibians (Cypher 2003); therefore they may show more plasticity in foraging success in areas with low food resources or high competition. The coexistence of red foxes and coyotes in the southwest Yukon lowlands was attributed, in part, by the elasticity in red fox prey selection (Theberge and Wedeles 1989). In contrast, aggressive behavior by coyotes towards red foxes was greater in the presence of a carcass than not (Gese et al. 1996).

In regards to reproduction, dens for each species are typically established within the thickest cover and most concealed areas of the landscape to avoid other predators (Anderson and Lovallo 2003; Bekoff and Gese 2003). Bobcat dens have been found in depressions at the base of stumps, beneath brush piles, or in heavily wooded areas with rocky terrain (Kitchings and Story 1984). Coyotes used pinyon-juniper and shrub-grassland habitats for bedsites, dens and rendevous sites due to heavy cover (Gese et al. 1988). Red foxes will dig their own dens, and at times use dens abandoned by other species (Cypher 2003). Mortality for these species occurs in large part to human exploitation. However, other mortality factors include starvation, predation, collisions with motor vehicles, and diseases (Anderson and Lovallo 2003; Bekoff and Gese 2003, Cypher 2003).

Previous studies have shown that resource use and partitioning of those resources varies by geographic location, seasonal changes, and association with other wildlife. Co-existence among sympatric red foxes, coyotes, and bobcats occurs much through partitioning of food resources and use or avoidance of habitat types. Reduction and fragmentation of habitat can have profound effects on the attributes of the landscape, which can directly or indirectly affect species populations.

2.2 Remote Sensing and Geographic Information Systems

The landscape in North America is constantly changing with the expansion of urban development, and ecosystems are being lost or degraded at high rates. Biologists and wildlife managers must constantly monitor natural resources and wildlife populations to ensure biological diversity, taking into consideration the natural history of species and the effects of landscape changes on wildlife. Remote sensing and geographic information system (GIS) technologies have become widely used by biologists in gathering information to help make informed wildlife management decisions.

2.2.1 *Remote Sensing*

Remote sensing is defined as the art and science of obtaining information about the Earth's physical features without having direct physical contact with those features. This is accomplished by the use of satellites and aircraft as platforms which carry sensors and cameras, respectively, to capture images. Images taken by aircraft may have higher resolution. For example, digital orthophoto quadrangles derived from aerial photography that are provided by the U.S. Geological Survey (USGS) are useful for interpreting features. Satellites, on the other hand, acquire digital images by collecting the electromagnetic energy reflected or emitted from objects. Satellite imagery, available in raster data format, consists of multiple channels or bands within the electromagnetic spectrum that are represented by a matrix, or pixel elements, containing brightness values based upon the radiometric resolution of the sensor (Jensen 2000).

The scale of multispectral imagery is determined by the spatial resolution, or the amount of area covered in one pixel. Spatial resolution varies among satellites, such as the fine 4 × 4 m spatial resolution of multi-spectral band images from the IKONOS satellite, or the coarse 1 × 1 km resolution imagery acquired by MODIS (Jensen 2000). Hence, the scale of analysis one can conduct with remote sensing data is limited by the spatial resolution of an image. For example, MODIS data is more appropriate at a global to regional scale as in the land cover mapping study by Wessels et al. (2004), while Landsat Thematic Mapper (TM) data is more suitable at a regional to local landscape scale (Driese et al. 1997).

A primary use for satellite imagery is to perform land cover classification for an area of interest as a primer for analysis of vegetation or habitat use. Classification of multi-spectral imagery is the process in which pixels with certain spectral characteristics are assigned to a particular feature class, which are then represented as colors to create a thematic image. Ecologists often conduct their own land cover classification, typically using Landsat TM data. However, some classified data sets are readily available through various agencies. The GAP Analysis Project (GAP), initiated as a pilot by researchers from the University of Idaho Cooperative Fish and Wildlife Research Unit (USGS nbii 2006), is a national collaboration among Federal, State, and independent or non-profit agencies to provide accurately classified land cover data for use in maintaining plant and animal biodiversity in this country.

Classified Landsat TM and other remote sensing data have been incorporated in numerous ecological studies involving birds and mammals, and various other applications. Driese et al. (1997) created a land cover map of Wyoming for the GAP Analysis program, to determine the distribution of vegetation cover types throughout the state and their landscape characteristics, examine regional trends in the elevation of montaine treelines, and examine summer precipitation effects on grasses and shrubs in Wyoming basins. Supervised and unsupervised classification was performed on Landsat TM data by Lauver (1997) to classify types of rangeland vegetation, and determine the areas of high and low quality grassland based on frequency of grazing. Final maps supported an earlier hypothesis that overgrazing leads to low quality grasslands with reduced cover and low species diversity. Edwards et al. (1996) used species lists of all terrestrial vertebrates found in Utah to create wildlife-habitat relationship models, by predicting presence or absence, for eight national parks in Utah, which were linked to Utah GAP data. The authors noted the linkage of the models with GAP data provided fairly reliable predictions of vertebrate distributions for all parks studied, but found that the models tended to over-predict the presence of some species. Hunter et al. (1995) used Landsat TM data to map and analyze land cover for a demographic study of the northern spotted owl (*Strix occidentalis caurina*) in northwestern California. Kremen et al. (2004)

conducted supervised classification of land cover, using training sets selected from georeferenced aerial photographs to investigate variation in crop pollination of organic and conventional farms by native, unmanaged bee communities.

2.2.2 *Geographic Information Systems*

A geographic information system (GIS) is a computer system used for entering, storing, manipulating, and visually representing digital data (Konecny 2003). Initially developed in 1963 as the Canadian Geographic Information System for creating an inventory of Canada's land resources, GIS has evolved over the last few decades as a tool used for academic, commercial, and general purposes with over one million estimated core users and five million casual users (Longley et al. 2001). Examples of GIS uses include defense and intelligence, geophysical exploration, construction projects, telecommunications and other utility management, business applications, and conservation and management of natural resources (Konecny 2003).

GIS allows several layers of spatial and attribute data with the same georeference to be displayed, manipulated and analyzed at the same time (Korte 1994). The data layers entered in a GIS can be raster and/or vector. The basic components of vector data are points, lines, and polygons that are defined by a series of coordinate pairs which may also have other dimensions, such as height, temperature, or some other measurement or value (Longley et al. 2001). Vector data consists of features that have been created through digitizing, a process in which locations are represented as points, and objects are created using endpoints, edges, and vertices (Ormsby et al. 2004). One example of vector data is the topologically integrated geographic encoding and referencing system (TIGER) that was originally designed for use with the 1990 U.S. census, but is more useful for non-census-related research (DeMers 1997).

Numerous studies have incorporated GIS to determine relationships between species and habitat use within their environment. Pendleton et al. (1998) used GIS to conduct compositional analysis of northern goshawk (*Accipiter gentilis*) habitat selection. Knick and Dyer (1997) used GIS to map Mahalanobis distances for black-tailed jackrabbit (*Lepus californicus*) mean habitat vectors and to validate the habitat model. Erickson et al. (1998) determined winter moose (*Alces alces*) habitat selection by analyzing the buffered habitat around group locations, and created a relative probability map of habitat distribution. Osborne et al. (2001) incorporated satellite imagery, a digital terrain model, and bird census data to model landscape-scale habitat use by great bustards (*Otis tarda*).

CHAPTER 3

DATA AND METHODOLOGY

Habitat quality and certain landscape characteristics are key to the survival of wildlife populations; the status of secondary and tertiary consumers are oftentimes indicators of the condition of the environment. Species may utilize particular niches within environments which helps partition resources; however sympatric species often compete for the same resources. Thus, research questions were formulated to address aspects of habitat affiliation among red foxes, coyotes, and bobcats.

As the scope of this study is to quantify the habitat relationships among these species, the scale, or extent, of the study was also considered for analysis. Tobler's First Law of Geography states "Everything is related to everything else, but near things are more related than distant things" (Longley et al. 2001). For example, the topography and land cover distribution in southern Illinois are quite different from central and northern Illinois. Extrapolating habitat affiliation to a scale beyond this region may increase error in interpretations, thus this study will be limited to a three-county area.

Collecting wildlife data on any scale is time-consuming and, depending on the study, may require expensive equipment. To alleviate these costs, it was decided that collecting sighting data by sampling of hunters could return an appropriate database for this study. Additional data, such as raster and vector data can be acquired for free from various sources. However, it is important that such data is suitable for analysis and is properly processed, and such steps were taken to ensure the integrity of additional data used in this study. Various methods of statistical analysis were implemented to measure the results of the data collected, and to produce and validate models for the species of interest. An illustration of the data collection and methodology used in this study is shown in Figure 3.1.

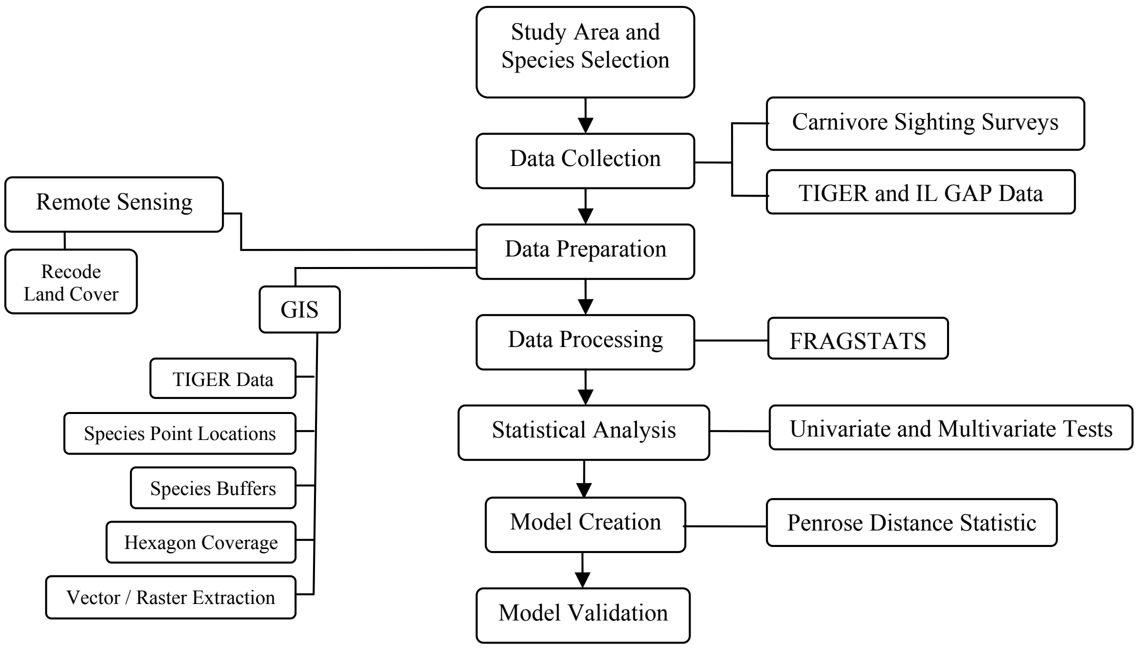

Fig. 3.1. Flowchart of data collection and methodology

3.1 Study Area

The study was conducted on a regional scale for the Illinois counties of Jackson, Williamson and Union; a land area totaling 370,000-ha (Figure 3.2). The tri-county area is located in southwestern Illinois, bounded by the coordinates: 89°41′38.02″W 37°57′39.16″N and 88°42′9.49″W 37°20′9.06″N. The western border of Jackson and Union counties begins at the Mississippi River and enters the Shawnee National Forest to the east; Williamson County encroaches upon the northern edge of the Shawnee National Forest.

Fig. 3.2. The tri-county study area in southern Illinois

These counties vary in the proportion of cover types, which are grouped into five general categories in the Land Cover of Illinois Statistical Summary 1999–2000 (Illinois Department of Agriculture 2005): agricultural land, forested cover, urban and built-up land, wetland, and other features (i.e. surface water, barren/exposed land). Based on classification of Landsat imagery through the Illinois Interagency Landscape Classification Project (2004), the average percentage of cover within the study area is: agriculture (55.2%), forests (25.1%), wetland (11.2%), urban and built-up land (4.2%), and other (4.3%). An extensive network of streams and secondary roads also lie within this region.

3.2 Primary Data Sources

3.2.1 *Carnivore Sighting Surveys*

Carnivore sighting surveys were used to acquire location data for red foxes, coyotes, and bobcats throughout the study area. Data for this study were collected from the results of two separate surveys. The surveys were funded through the Cooperative Wildlife Research Laboratory, Southern Illinois University Carbondale (SIUC), and conducted within protocol approved by the Human Subjects Committee at SIUC (File #05078).

3.2.2 *Survey Design*

3.2.2.1 Survey Target Group

The target groups for these surveys were firearm deer hunters. Hunters were selected as participants for the survey because many of them spend much time in the field, and the average hunter should be knowledgeable of wildlife to correctly identify carnivores. A total of 17,811 permits were granted for the 2004 Illinois Firearm Deer hunting season for all three counties; some hunters received more than one permit for the season. The categories of permits available were broken down as such:

- Muzzle Loader Antlerless
- Muzzle Loader Either Sex
- Shotgun Antlerless
- Shotgun Either Sex
- Shotgun Non-Resident Land Owner/Tenant Antlerless
- Shotgun Non-Resident Land Owner/Tenant Either Sex

- Shotgun Property-Only Hunting Land Owner/Tenant

Hunters who participated in the firearm deer season were required to report their harvested game at deer check stations within the county they hunted. Deer check stations were operated by the Illinois Department of Natural Resources.

3.2.2.2 *Hunter Database Acquisition*

Each deer check station recorded physiological information of deer brought in by each hunter, including sighting information of other wildlife. Volunteers who assisted in processing deer data inquired if hunters observed red foxes, coyotes, and/or bobcats while hunting, and recorded this information on deer check sheets. The hunter's permit tag was affixed to the check sheet along with the recorded information; the tags contained the name of the hunter and their address. Deer check sheets were collected from check stations within the study area, and hunters who observed any of the carnivores were entered into a spreadsheet. The information entered included: hunting date, hunter name and address, species observed and number, check station location, and county of deer harvest.

3.2.2.3 *Hunter Selection*

The hunters selected for participation in the survey were based on residence status. Hunters that did not have Illinois addresses were eliminated from the database. I established this method of hunter selection based on two assumptions: 1) Illinois non-resident hunters may not be as familiar with the study area as Illinois resident hunters, and 2) non-resident hunters may potentially increase marking errors on the surveys. A total of 562 hunters who checked in at the deer stations observed at least one of the carnivores. Thirty-nine of those hunters had addresses outside of Illinois and were removed from the survey mailing list.

3.2.2.4 *Survey Design*

The carnivore sighting surveys were conducted for the 2004 and 2005 hunting years. The dates of the 2004 Firearm Deer season were November 19–21 and December 2–5, and the 2005 Firearm Deer season occurred November 18–20 and December 1–4. All Illinois resident-only hunters were mailed a photocopied plat map (see Appendix B–D) of the county they hunted in, along with a letter explaining how their name was collected and the purpose of the survey. The letter asked the hunter to mark the approximate location of carnivores sighted while hunting and identify which species was observed for each location. A self-addressed, postage-paid envelope was included for hunters to return their surveys. Surveys for the 2004 hunting year were mailed April 7, 2005, and collected through August 31, 2005; the location data acquired during this survey were used for building the species-habitat models. Surveys for the 2005 hunting year were mailed December 6, 2005, and collected through February 28, 2006; the location data acquired from this survey were used to validate the models.

Reminders to complete the survey were mailed to hunters by way of postcards. The goals of the reminders were to thank hunters for participating in the survey, and to encourage participation for those that had not responded. Postcards were mailed four weeks after initial mailing of the 2004 season surveys, and two weeks after the 2005 season surveys were mailed.

3.2.2.5 *Survey Modification*

During the 2005 Firearm Deer season, the Illinois Department of Natural Resources changed the method of reporting deer harvest to telephone or internet reporting for most Illinois counties, including Jackson, Union, and Williamson. In order to acquire carnivore location data for model validation, surveys were mailed using the same hunter database from the 2004 hunting year, including a photocopied plat map of the county they hunted in that year. The accompanying letter was modified with an offer to send the hunter another map, upon request, if they hunted in a different county within the study area from the previous year.

3.3 Secondary Data Sources

Land cover classification is an extensive process which entails image preprocessing, *in situ* data collection, collecting training samples, applying a classification algorithm, and then performing accuracy assessment (Jensen 2005). I chose to use classified land cover data from another source to reduce the data processing time for this study. Classified Illinois GAP Analysis land cover data from the Illinois Natural History Survey (2003) was acquired for habitat and other land feature coverage within the study area.

Not all roads and streams were represented in the Illinois GAP data, therefore Census 2000 TIGER/Line® shapefiles for secondary county roads and streams were acquired for each county from the ESRI Data website (Environmental Systems Research Institute 2005), to assist in GIS placement of carnivore sighting locations and assess the density of these features in the study area.

3.4 Remote Sensing and GIS Techniques

3.4.1 *Remote Sensing Techniques*

The Illinois GAP data (Illinois Natural History Survey 2003) was produced from Landsat TM/ETM+ unsigned 8-bit radiometric resolution, 30m spatial resolution imagery captured in 1999 and 2000, and classified using the Anderson classification system (Anderson et al. 1976). A Slope Aspect Index was applied to the image using a USGS 3 arc-second digital elevation model (DEM) prior to classification to distinguish between upland and floodplain forests (Illinois Natural History Survey 2003). The original land cover data was classified into five Level I classes and 31 Level II subclasses (Table 3.1).

Table 3.1. Classification of Illinois GAP analysis land cover (Illinois Natural History Survey 2003)

Level I	Level II
1 Agricultural Land	11 Corn
	12 Soybeans
	13 Winter wheat
	14 Other Small Grains and Hay
	15 Winter Wheat/Soybeans
	16 Other Agriculture
	17 Rural Grassland
2 Forested Land	21 Upland
	22 Upland: Dry
	23 Upland: Dry-Mesic
	24 Upland: Mesic
	25 Partial Canopy/Savanna Upland
	26 Coniferous
3 Urban and Built-Up Land	31 High density
	32 Low/Medium Density
	33 Low/Medium Density: Medium
	34 Low/Medium Density: Low
	35 Urban Open Space
4 Wetland	41 Shallow Marsh Wetland
	42 Deep Marsh
	43 Seasonally/Temporarily Flooded
	44 Floodplain Forest
	45 Floodplain Forest: Mesic
	46 Floodplain Forest: Wet-Mesic
	47 Floodplain Forest: Wet
	48 Swamp
	49 Shallow Water
5 Other	51 Surface Water
	52 Barren and Exposed Land
	53 Clouds
	54 Cloud Shadows

While there are characteristics which do separate some of the Level II classes, these classes are not exclusive to any of the species in this study. Thus, many of these Level II classes were combined to create more generalized land cover classes and allow for a less complex analysis of habitat relationships. Using ERDAS Imagine 8.7 (Leica Geosystems 2003), the thematic raster image of 31 classes was recoded to six land cover classes

(Table 3.2): agricultural land, rural grassland, forest, urban and built-up land, wetland, and water (Figure 3.3).

Table 3.2. Classification of Illinois GAP analysis land cover after recoding

Level I	Level II
1 Agricultural Land	11 Corn
	12 Soybeans
	13 Winter wheat
	14 Other Small Grains and Hay
	15 Winter Wheat/Soybeans
	16 Other Agriculture
2 Rural Grassland	
3 Forested Land	31 Upland
	32 Upland: Dry
	33 Upland: Dry-Mesic
	34 Upland: Mesic
	35 Partial Canopy/Savanna Upland
	36 Coniferous
4 Urban and Built-Up Land	41 High density
	42 Low/Medium Density
	43 Low/Medium Density: Medium
	44 Low/Medium Density: Low
	45 Urban Open Space
	46 Barren and Exposed Land
5 Wetland	51 Shallow Marsh Wetland
	52 Deep Marsh
	53 Seasonally/Temporarily Flooded
	54 Floodplain Forest
	55 Floodplain Forest: Mesic
	56 Floodplain Forest: Wet-Mesic
	57 Floodplain Forest: Wet
	58 Swamp
6 Water	61 Surface Water
	62 Shallow Water

*Clouds and cloud shadows were not present in the study area.

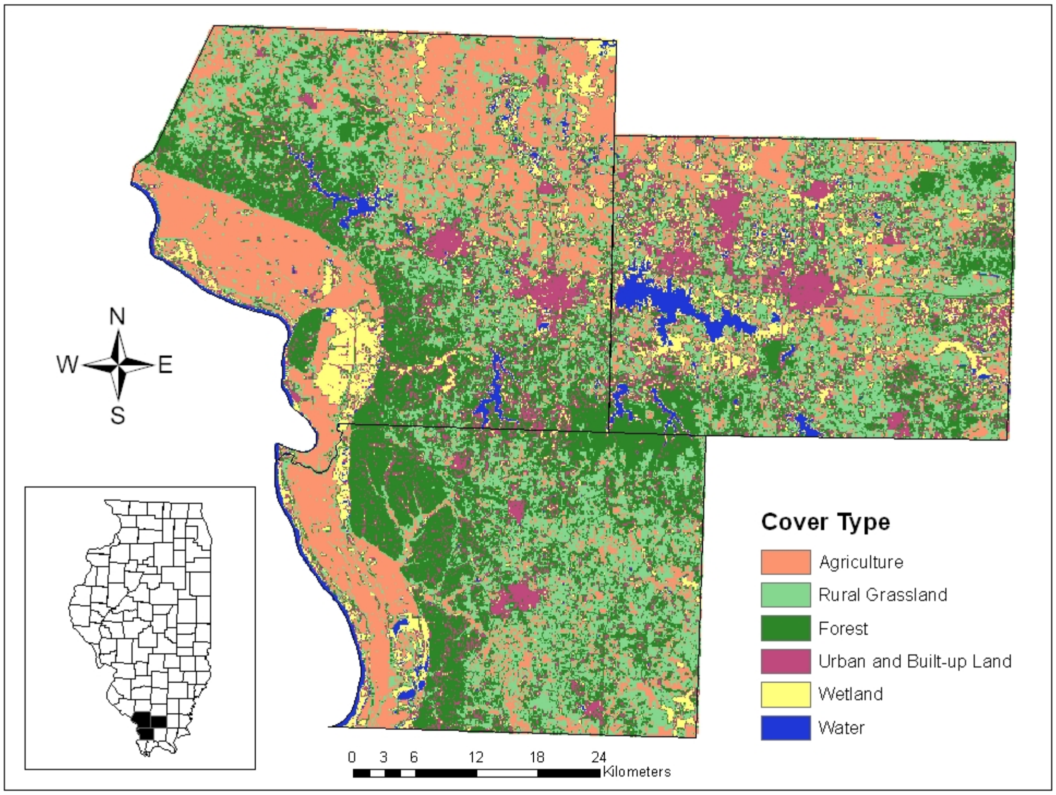

Fig. 3.3. Recoded Illinois GAP land cover for the study area

A subset image of the study area was created to incorporate only the study area and outlying areas to reduce the file size; this image was converted to GRID format for processing in ArcView and FRAGSTATS. The original NAD83 UTM Zone 16N projection was retained to conduct spatial analysis.

3.4.2 *GIS Techniques*

The TIGER/Line® data were reprojected to match the Illinois GAP raster data. The stream layers included polygons representing ponds and lakes; these were deleted to avoid inclusion with stream density calculations (Figure 3.4). Road and stream layers were appended to create one contiguous layer for each feature.

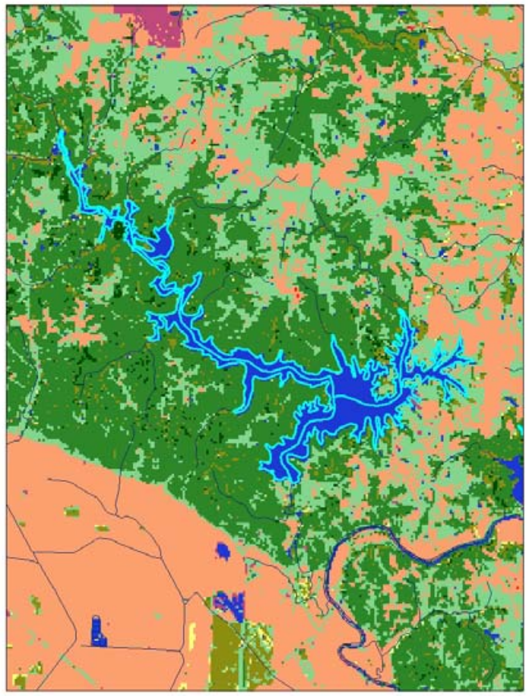

Fig. 3.4. Lake selected to remove from density calculations

Locations for species marked on returned maps were entered as point data into a GIS database to assist in generating regional habitat models. Point shape files projected to NAD83 UTM Zone 16N were created in ArcGIS 9.0 (Environmental Systems Research Institute 2004) for each species to mark species point locations, and then added with road and stream vector data for the three counties in ArcMap. Roads and streams shown on the returned survey plat maps were cross-referenced with the vector data to determine the approximate location for placement of carnivore point locations. The following criteria were used regarding the use of hunter-marked species locations and point placement in GIS:

- Maps with unidentified marked locations were discarded.
- Single marks identifying one or more species were represented as one point for each species, regardless of the number of individuals sighted.
- Two marked locations in close proximity, for two species without specific identification, were represented as one point for each placed between both marks.
- Two or more marked locations in close proximity, identified as the same species, were represented as one point placed in the center of all marks.

The point shapefile attribute tables were edited to add ID numbers and X-Y coordinates. Circular buffers of 1-km^2 (radius = 564 m) were created for all 2004 carnivore locations, using the carnivore point locations as centroids (Figure 3.5). The average home range sizes of these species range from 8.6-19.9 km^2, 2.1-68.0 km^2, and 2.0-112.2 km^2 for red foxes, coyotes, and bobcats, respectively (Cypher 2003, Bekoff and Gese 2003, Anderson and Lovallo 2003). I believed a 1-km^2 area was appropriate for sampling land cover and features within a smaller portion of an individual's range to discern characteristics unique to each species over a larger area. ArcView 3.3 (Environmental Systems Research Institute 2002) was used to clip the recoded GAP data from individual buffers for each species, allowing each area to be analyzed separately (Figure 3.6).

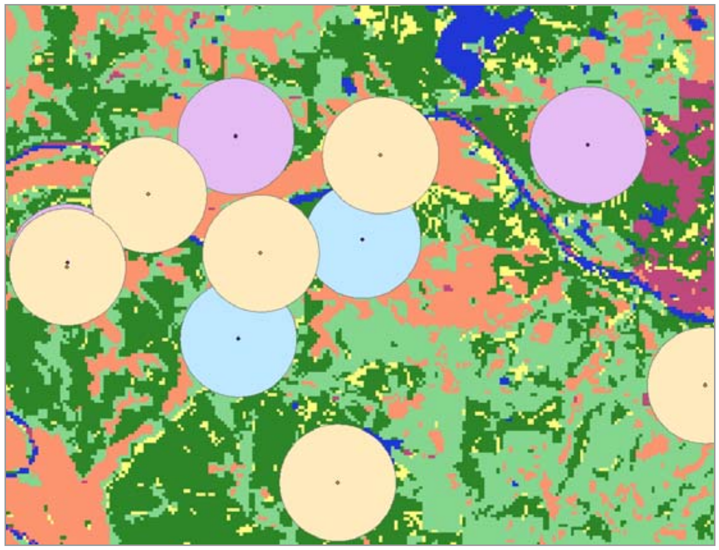

Fig. 3.5. Carnivore buffers (1-km²) with their respective centroids

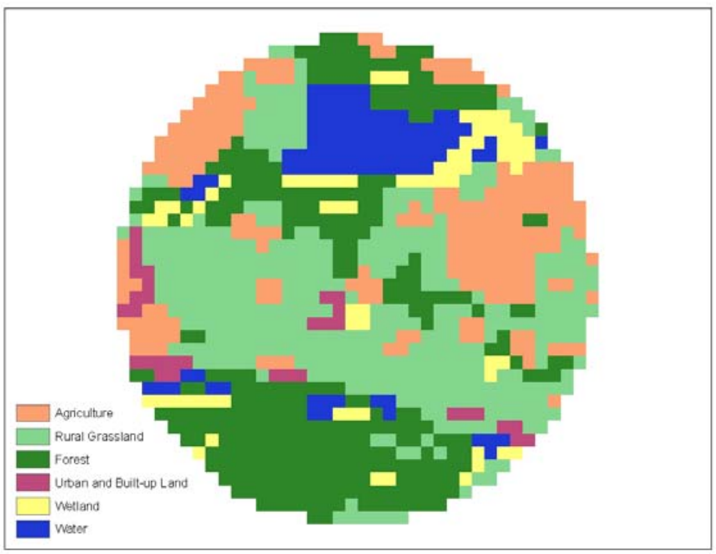

Fig. 3.6. Example of GAP data extracted from a species buffer

Road and stream data were individually extracted from the species buffers using the Intersect tool in ArcMap, and imported in a geodatabase to calculate density of these features per buffer.

A continuous non-overlapping hexagon grid layer was created for the study area using a Repeating Shapes script from the ESRI Support Center website (Environmental Systems Research Institute 2006). The parameters selected for the grid layer were for hexagons 1-km² in area, with a 0-degree offset angle (Figure 3.7). Only hexagons that had their center within the study area were selected to represent the study area. Recoded GAP data and roads were extracted from each hexagon for quantifying landscape structure over the entire study area. ArcMap was used to generate maps to display all model results.

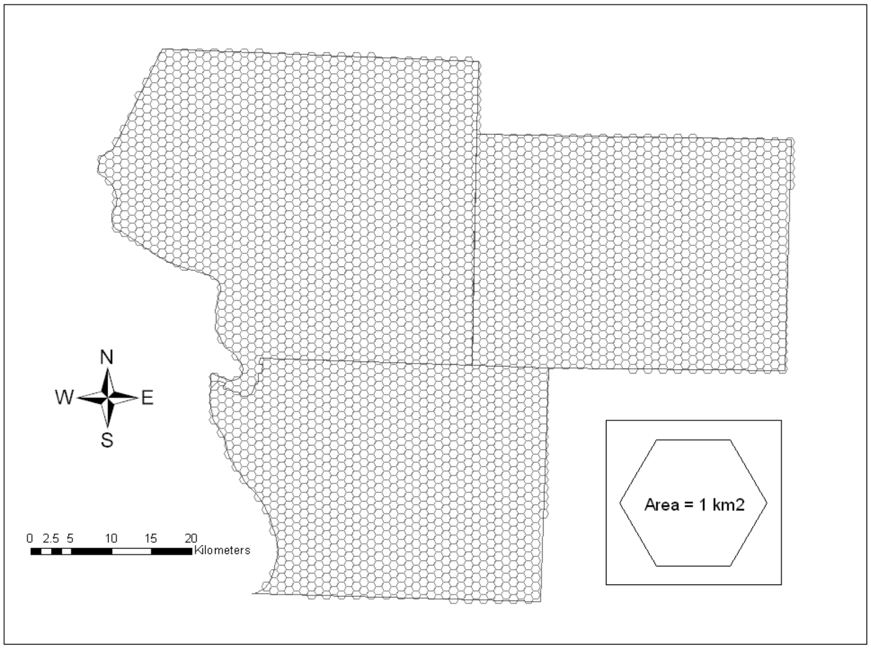

Fig. 3.7. Hexagon coverage over the study area

3.5 Habitat Modeling

Several variables were selected to determine habitat affiliations among the carnivore species based on potential biological importance. A series of statistical tests were performed to eliminate non-significant variables from analysis, and determine which significant variables to be used for modeling. Models were run to produce and validate results from significant variables.

3.5.1 *Selection and Calculation of Habitat Variables*

FRAGSTATS (McGarigal et al. 2002) was used to quantify GAP landscape structure within individual raster buffer areas for each species and hexagons covering the study area, generating variables to create the carnivore-habitat models. Seven class-level metrics for each land cover type and eight landscape-level metrics were selected for analysis (Tables 3.3 and 3.4). The terms *class* or *classes* refer to land cover types created through recoding of the original GAP data. The term *landscape*, stated in the metric descriptions, refer to the GAP data within each species buffer or hexagon in this study; and *patch* or *patch type* refers to a particular land cover class within the *landscape*. In addition to the FRAGSTATS metrics, the lengths of road and stream features contained in species buffers and hexagons were used to calculate density in Microsoft® Excel for analysis, where:

<u>Road Density (m/ha)</u> – The total distance of roads (m), divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).

<u>Stream Density (m/ha)</u> – The total distance of streams (m), divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).

Batch files were created for each species and the hexagon outputs, as well as a class properties file to establish parameters for the extracted data. FRAGSTATS produced comma-delimited outputs that were imported into Microsoft® Excel and the values were sorted for statistical analysis.

Table 3.3. Selected class metrics, corresponding units measured, and descriptions from FRAGSTATS (McGarigal et al. 2002)

Metric	Level	Units	Description
Percentage of Landscape (PLAND)	Class	%	The sum of the areas (m^2) of all patches of the corresponding patch type, divided by the total landscape area (m^2), multiplied by 100 (to convert to a percentage).
Edge Density (ED)	"	m/ha	The sum of the lengths (m) of all edge segments involving the corresponding patch type, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).
Mean Patch Area (AREA_MN)	"	ha	The sum of the areas (m^2) of all patches of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares).
Mean Patch Fractal Dimension (FRAC_MN)	"	none	The sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch of the corresponding patch type, divided by the number of patches of the same type.
Mean Core Area (CORE_MN)	"	ha	The sum of the core areas of each patch (m^2) of the corresponding patch type, divided by the number of patches of the same type, divided by 10,000 (to convert to hectares).
Mean Proximity Index (PROX_MN)	"	none	The sum of patch area (m^2) divided by the nearest edge-to-edge distance squared (m^2) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch, summed across all patches of the same type and divided by the total number of patches in the class.
Interspersion and Juxtaposition Index (IJI)	"	%	Minus the sum of the length (m) of each unique edge type involving the corresponding patch type divided by the total length (m) of edge (m) involving the same type, multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types minus 1; multiplied by 100 (to convert to a percentage).

Table 3.4. Selected landscape metrics, corresponding units measured, and descriptions from FRAGSTATS (McGarigal et al. 2002)

Metrics	Level	Unit	Definition
Edge Density (ED)	Landscape	m/ha	The sum of the lengths (m) of all edge segments in the landscape, divided by the total landscape area (m^2), multiplied by 10,000 (to convert to hectares).
Mean Patch Fractal Dimension (FRAC_MN)	"	none	The sum of 2 times the logarithm of patch perimeter (m) divided by the logarithm of patch area (m^2) for each patch in the landscape, divided by the number of patches.
Mean Patch Area (AREA_MN)	"	ha	The total landscape area (m^2), divided by the total number of patches, divided by 10,000 (to convert to hectares).
Mean Core Area (CORE_MN)	"	%	The sum of the proportion of each patch that is core area, divided by the number of patches, multiplied by 100 (to convert to a percentage).
Mean Proximity Index (PROX_MN)	"	none	The sum of patch area (m^2) divided by the squared nearest edge-to-edge distance (m) between the patch and the focal patch of all patches of the corresponding patch type whose edges are within a specified distance (m) of the focal patch, summed across all patches in the landscape and divided by the total number of patches.
Interspersion and Juxtaposition Index (IJI)	"	%	Minus the sum of the length (m) of each unique edge type divided by the total landscape edge (m), multiplied by the logarithm of the same quantity, summed over each unique edge type; divided by the logarithm of the number of patch types times the number of patch types minus 1 divided by 2; multiplied by 100 (to convert to a percentage).
Shannon's Diversity Index (SHDI)	"	none	Minus the sum, across all patch types, of the proportional abundance of each patch type multiplied by that proportion.
Shannon's Evenness Index (SHEI)	"	none	Minus the sum, across all patch types, of the proportional abundance of each patch type squared, divided by 1 minus the quantity 1 divided by the number of patch types.

3.5.2 *Univariate Statistical Analysis*

The values calculated from the FRAGSTATS metrics and road and stream density, were imported in JMP 6.0 (SAS Institute 2005) to perform a Kruskal-Wallis ANOVA ($\alpha = 0.05$ throughout). This test was to determine which variables differed among hexagons where the three species were sighted and eliminate non-significant variables from analysis ($\alpha = 0.05$ throughout). Kruskal-Wallis ANOVA is a non-parametric test for data that does not meet the assumptions of a parametric ANOVA (Sokal and Rohlf 1995). A post hoc Z-test was conducted on the significant variables using STATISTIX 8.1 (Analytical Software 2003) to determine pairwise differences between species' means. Spearman's rank correlations were conducted to determine and eliminate highly correlated ($r > 0.55$) variables from further analysis.

3.5.3 *Multivariate Statistical Analysis*

A multinomial logistic regression was conducted on the same variables tested under univariate analysis using SPSS 14.0 (SPSS Inc. 2006). My goal was to determine whether a multivariate statistical model could differentiate among these species in terms of the chosen habitat variables. Results for the Cox and Snell, Nagelkerke, and McFadden R^2 tests were <0.052, indicating very poor model fit. Hence, I did not explore these results further.

3.5.4 *Penrose Distance Model*

The Penrose distance statistic was used to create categorical maps to indicate similarity between the mean habitat vectors for each species and habitat within the rest of the study area (Nielsen and Woolf 2002); the mean habitat vectors are the buffered areas surrounding each species location point. The mean habitat vectors encompass an area of 1-km² (radius = 564 m) in this study. Penrose distance is similar to Mahalanobis distance, except it does not take into consideration correlations between variables (Manly 1994), which I accounted for with the aforementioned correlation analysis. Penrose distance values for the variables which tested significant through univariate statistical analyses were calculated according to the following equation (Manly 1994):

$$P_{ij} = \sum_{k=1}^{p} \frac{(\mu_{ki} - \mu_{kj})^2}{pV_k}$$

Where:

i = core areas
j = study area hexagons
μ = mean of the variable
k = each observation
p = number of variables evaluated
V = variance of the variable

Penrose distance maps were created for each species, depending upon whether an appropriate number of variables varied among species. This was accomplished by assigning the summed Penrose values of the variables to their respective study area hexagons. Percent differences between species' Penrose distance values were then calculated for each hexagon, and then mapped to show the distribution of areas with the highest habitat affiliation among species. Two additional Spearman's rank correlations were then conducted to determine correlations between species and habitat variables, and correlations between Penrose percent differences and habitat variables. The species-habitat variable correlation was conducted to determine how the species were correlated to each variable, while the Penrose percent difference-habitat variable correlation was to determine which variables were attributed to the greatest percent differences between species.

CHAPTER 4

RESULTS

This chapter presents the results from the carnivore sighting surveys, including the location data collected for each species. The results of multivariate and pot hoc tests are also included. Finally, Penrose distance maps are presented in the last section with a description of species-habitat affiliations.

4.1 Carnivore Sighting Surveys

4.1.1 *Survey Response*

Deer firearm check sheets were collected from eight check stations within the study area. A total of 562 hunters had observed at least one of the three carnivores during the 2004 hunting season. Surveys were mailed to 523 (93.1%) of the Illinois resident-only hunters from the 2004 season, and surveys were mailed to 520 hunters for the 2005 season. The total number of responses for years 2004 and 2005 were 209 and 151, respectively (Table 4.1). The response rate for years 2004 and 2005 were 40.3% and 29.1%, respectively (Figure 4.1 and 4.2). Nearly 38% of the responses from the 2005 survey were discarded, compared to 9% discarded from the 2004 season. It is important to note that the high number of discarded responses (43) from the 2005 season was due to the fact that hunters did not observe any of the carnivores while hunting or did not hunt that season, but returned their map or cover letter with comments. All discarded responses from the 2004 season were as a result of maps with unidentified marked locations.

Table 4.1. Hunter survey results by year

	2004	2005
Total Surveys Mailed	523	520
Non-deliverable Surveys	4	1
Number of Responses	209	151
Response Rate	40.0%	29.0%

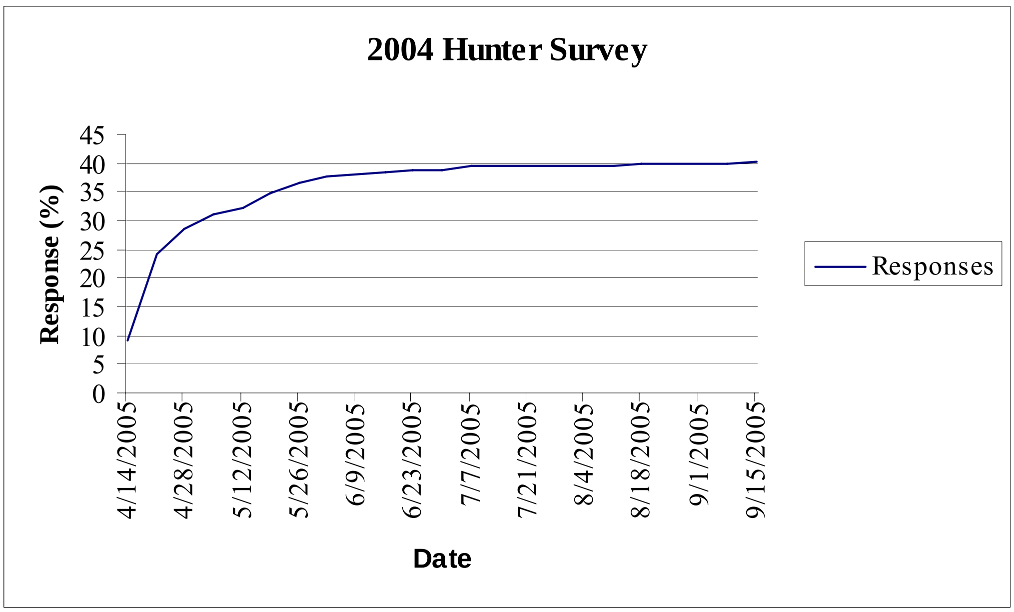

Fig. 4.1. Hunter response for the 2004 season

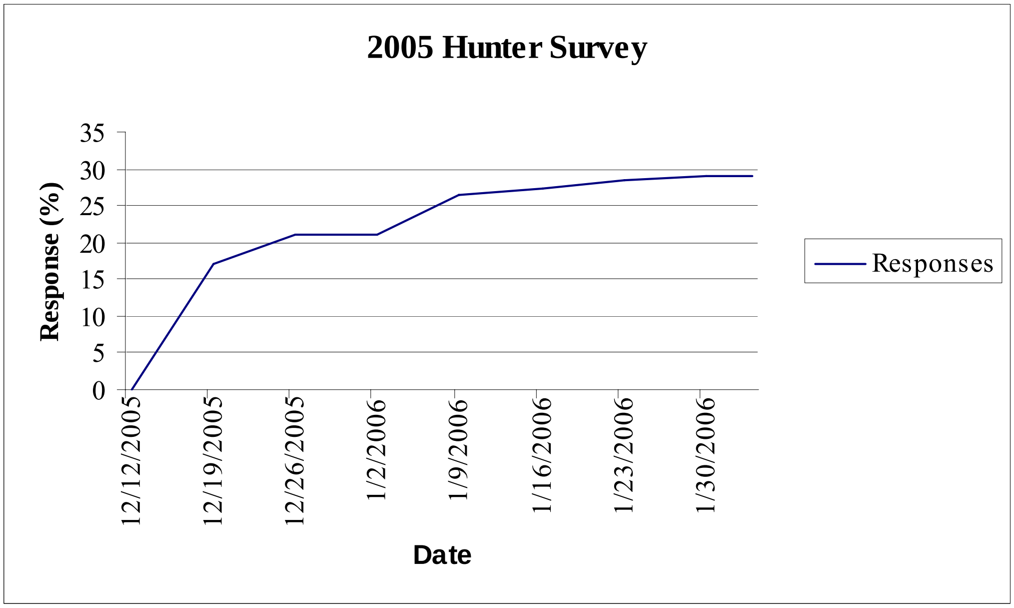

Fig. 4.2. Hunter response for the 2005 season

4.1.2 *Carnivore Sighting Data*

Despite the relatively low survey response rate, there was a sufficient amount of data available to produce and validate the models. Though not every coyote and bobcat sighting were represented as point locations, more coyotes were observed, followed by bobcats and red foxes; all red fox sightings were represented as point locations (Table 4.2). In 2004, 11.4%, 49.8% and 38.8% of the total point locations created were for red foxes, coyotes and bobcats, respectively. In 2005, 12.8%, 54.8% and 32.4% of the total point locations created were for red foxes, coyotes and bobcats, respectively.

Table 4.2. Total species point locations for 2004 and 2005

	Species		
Hunting Year	Red Fox	Coyote	Bobcat
2004	47	205	160
2005	28	120	71

4.2 Statistical Analysis

4.2.1 *Variable Reduction*

Nine variables differed among the three species (Table 4.3). Red foxes show higher grassland use, while bobcats have a strong association for forests. Red foxes have slightly increased use of urban surroundings than bobcats and coyotes. Road density use was higher for red foxes. Coyote means fell between red fox and bobcat means for all variables.

Table 4.3. Nine of 52 variables tested were significant

Variable	Species	Mean	SD	X^2	*P*-value
PLAND of grassland cover	Bobcat	23.3	17.0	8.2	0.0165
	Coyote	25.9	18.2		
	Red fox	32.2	20.1		
AREA_MN of grassland cover	Bobcat	3.4	4.3	7.8	0.0206
	Coyote	4.7	8.9		
	Red fox	8.0	16.1		
CORE_MN of grassland cover	Bobcat	1.3	2.3	7.5	0.0230
	Coyote	2.1	5.9		
	Red fox	4.1	11.0		
IJI of forest cover	Bobcat	66.9	16.8	8.2	0.0162
	Coyote	63.8	20.8		
	Red fox	59.2	15.6		
CORE_MN of urban cover	Bobcat	0.2	0.8	6.4	0.0415
	Coyote	0.3	2.3		
	Red fox	0.5	1.8		
PROX_MN of urban cover	Bobcat	1.2	6.1	6.4	0.0402
	Coyote	1.4	7.1		
	Red fox	4.2	14.0		
FRAC_MN of wetland cover	Bobcat	1.1	0.1	8.2	0.0164
	Coyote	1.0	0.2		
	Red fox	1.0	0.2		
FRAC_MN of the landscape	Bobcat	1.1	0.1	8.9	0.0117
	Coyote	1.1	0.1		
	Red fox	1.1	0.1		
Road density	Bobcat	12.0	10.3	12.4	0.0020
	Coyote	14.3	13.5		
	Red fox	19.7	14.4		

SD – standard deviation

There were no differences ($P > 0.05$) among species for mean core area and mean proximity index of urban cover (Table 4.4). Seven variables were different between red foxes and bobcats. Only one significant variable was different between red fox-coyote and bobcat-coyote pairings, respectively. This illustrates that coyote habitat affiliation overlaps almost entirely with that of bobcats and red foxes, respectively, therefore it was decided that Penrose distance maps were needed to represent habitat-relationships only for red foxes and bobcats.

Table 4.4. Matrix of significant pairwise differences ($P \leq 0.05$) among group means

	Red Fox	Coyote	Bobcat
Red Fox	—	—	—
Coyote	Only Road Density	—	—
Bobcat	All 7 Variables	Only Landscape FRAC_MN	—

Three variables were highly correlated ($r > 0.55$): percentage of grassland, mean patch area of grassland, and mean core area of grassland (Table 4.5). Percentage of grass was selected to represent the significance of grassland for easier interpretation, resulting in five final variables for habitat-relationship models.

Table 4.5. Spearman's rank correlation *r*-values for significant pairwise variables

	AREA_MN Grass	CORE_MN Grass	CORE_MN Urban	IJI Forest	FRAC_MN Landscape	FRAC_MN Wetland	PROX_MN Urban	PLAND Grass
CORE_MN Grass	0.98							
CORE_MN Urban	0.12	0.10						
IJI Forest	-0.28	-0.27	0.02					
FRAC_MN Landscape	0.02	-0.02	-0.10	0.16				
FRAC_MN Wetland	-0.16	-0.18	-0.02	0.22	0.42			
PROX_MN Urban	0.12	0.09	0.54	-0.05	-0.08	-0.02		
PLAND Grass	0.90	0.90	0.07	-0.23	-0.01	-0.20	0.10	
Road Density	0.00	-0.01	0.05	-0.01	0.02	0.01	0.11	-0.02

4.2.2 *Penrose Distance Models*

The variable means for the study area fell between the means for red fox and bobcat vectors (Table 4.6). Eighteen percent, 36%, and 64% of the red fox validation points fell within the top 10%, 25%, and 50% of Penrose distance values, respectively. For bobcats, 14%, 32%, and 65% of the validation points fell within the top 10%, 25%, and 50% of Penrose distance values, respectively.

Table 4.6. Mean and standard deviation (SD) of the variables used to model red fox and and bobcat habitat

Variable	Mean red fox vector[a]	Mean bobcat vector[b]	Study area[c]
IJI of forest cover	59.2±15.6	66.9±16.8	61.0±22.3
PLAND of grass cover	32.2±20.1	23.3±17.0	24.8±19.1
FRAC_MN of the Landscape	1.1±0.1	1.1±0.1	1.1±0.1
FRAC_MN of wetland cover	1.0±0.2	1.1±0.1	1.0±0.2
Road Density	19.7±14.4	12±10.3	16.9±17.9

[a] Calculated from 47 red fox vectors.
[b] Calculated from 160 bobcat vectors.
[c] Calculated from 3780 study area hexagons.

The red fox model shows areas of habitat affiliation are primarily in mixtures of agriculture and grassland (Figure 4.3). Red foxes avoided urban areas and large tracts of forest and agriculture, particularly along the Mississippi River floodplain. Bobcats appear to show more affiliation towards mixtures of grassland, wetland and forest (Figure 4.4). Like the red fox, bobcats also avoided urban areas and large tracts of agriculture. Hexagons with 25% or less difference in Penrose distance values for each species fell primarily within the Mississippi River floodplain, more homogeneous agricultural areas, and urban areas (Figure 4.5). These species habitat affiliations are also validated by rank correlations (Table 4.7). Bobcat habitat affiliations are influenced by forest and landscape patch size, whereas red foxes are most influenced by grassland. The distribution of habitat best suited for red foxes within the study area falls within the eastern half of Union County, the north- and south-central areas of Williamson County, and a diagonal strip of area from the northwest to southeast corners of Jackson County (Figure 4.5).

Table 4.7. Spearman's rank correlations (r) between habitat variables, Penrose distances, and percent differences for the study area hexagons

Variable	r - Red Fox	r - Bobcat	r - % Difference
IJI of forest cover	-0.12	-0.37	0.43
PLAND of grass cover	-0.51	-0.10	-0.54
FRAC_MN of landscape	-0.11	-0.33	0.37
FRAC_MN of wetland cover	-0.14	0.18	-0.51
Road Density	-0.09	-0.25	0.27

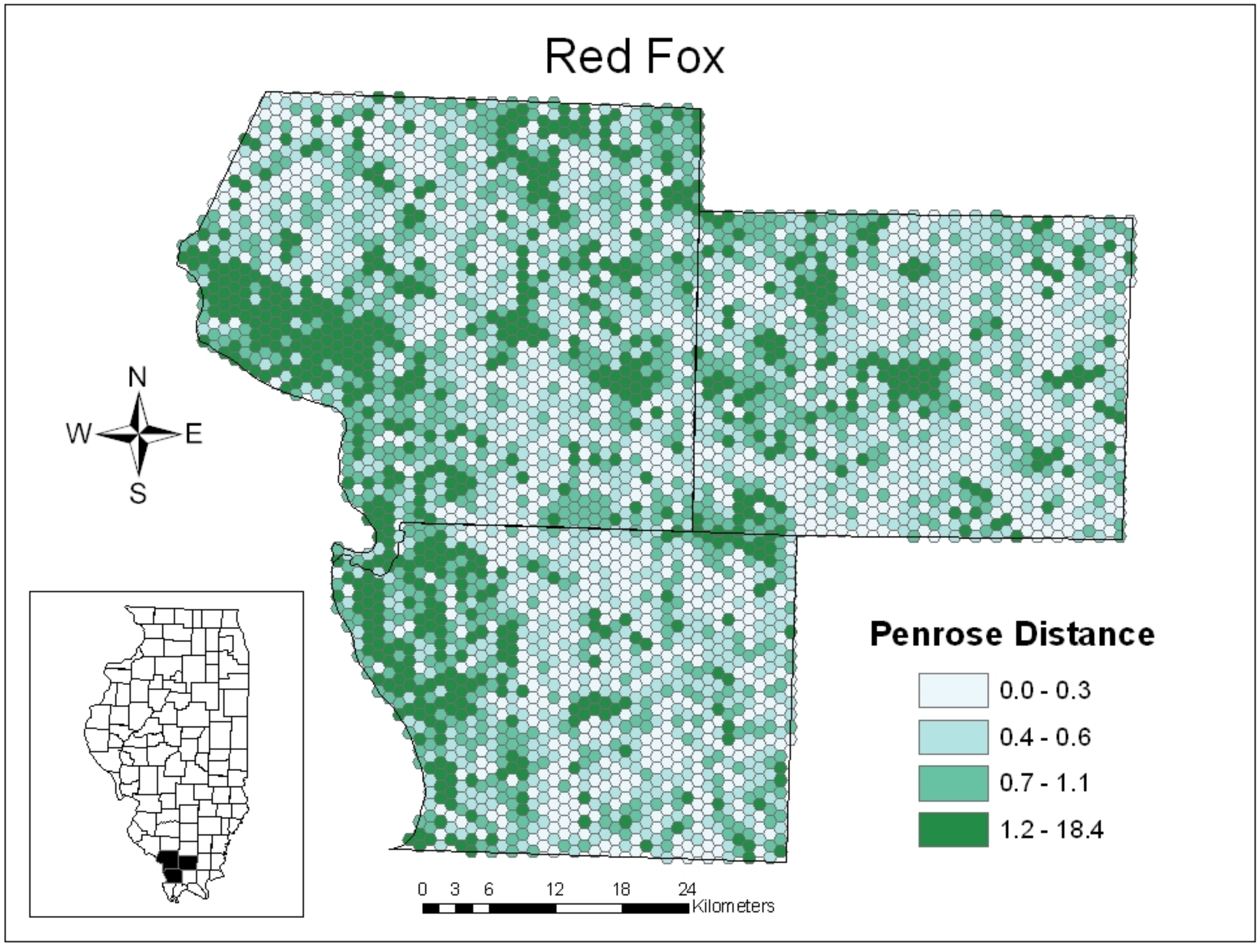

Fig. 4.3. Penrose distance map for red foxes; low Penrose values indicate areas with land cover closest to the mean habitat vectors

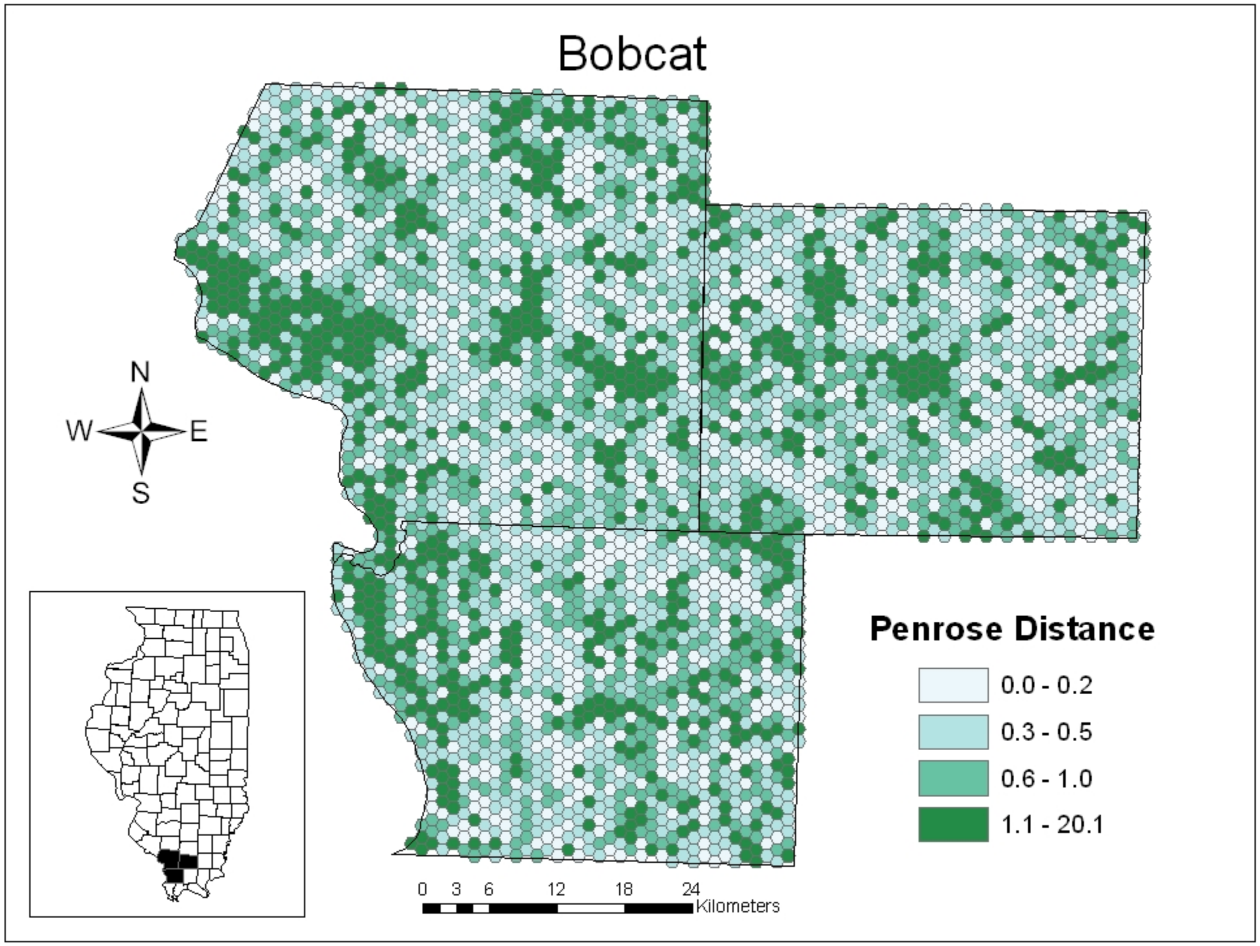

Fig. 4.4. Penrose distance map for bobcats; low Penrose values indicate areas with land cover closest to the mean habitat vectors

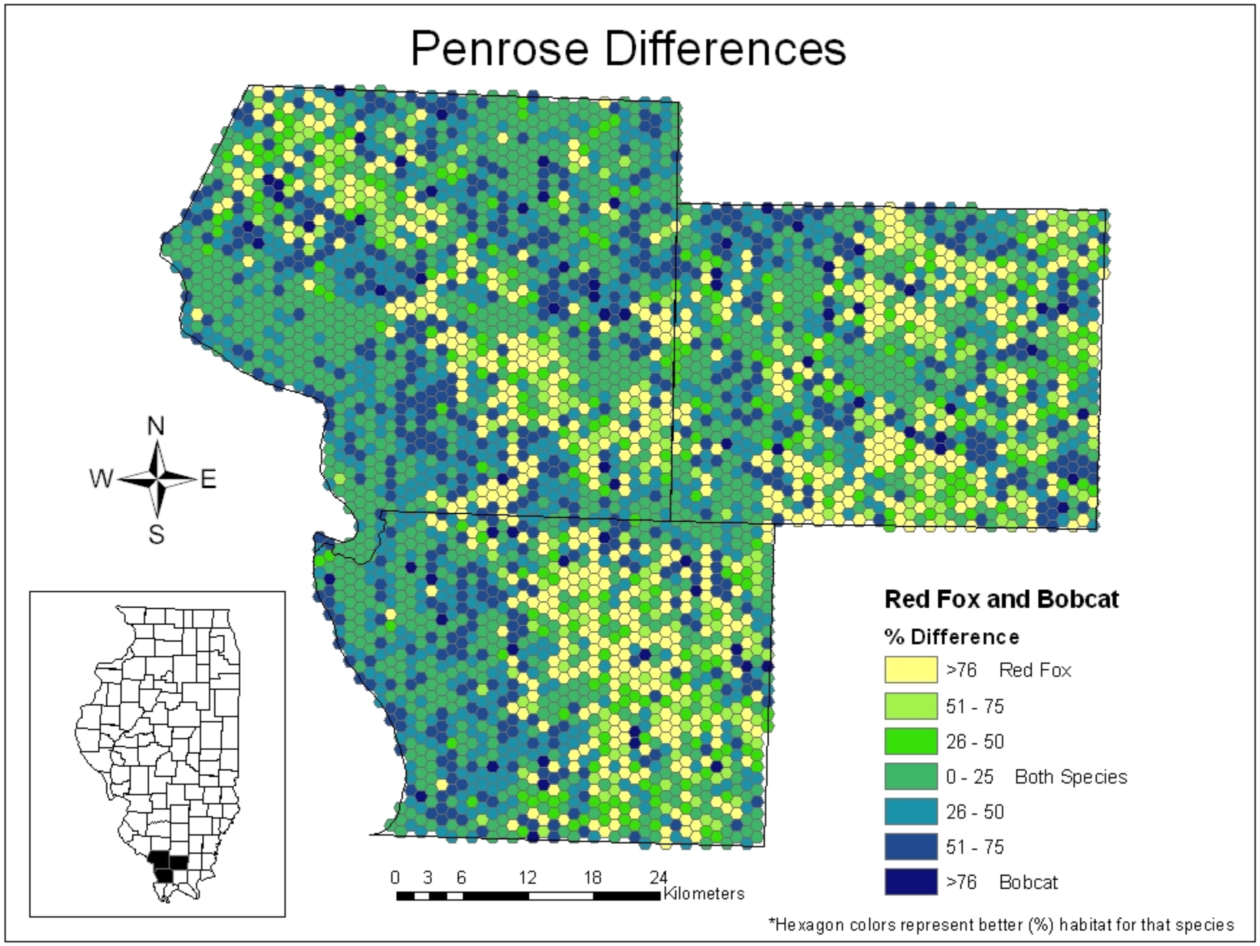

Fig. 4.5. The percent difference in Penrose distance values between red foxes and bobcats

CHAPTER 5

DISCUSSION AND CONCLUSION

5.1 Discussion

Researching wildlife, their roles in the ecosystem, and how they interact with each other is an ongoing process. It is also vital for maintaining healthy populations, particularly because of the continuing reduction of natural resources to support them. Ecologists, geographers, and spatial analysts are always looking for ways to gather information to help make informed management decisions. This study incorporated some of these methods to gain insight into species-habitat relationships among three sympatric carnivores in the southern Illinois region.

Sighting data is often incorporated (Stoms et al. 1993; Palma et al. 1999) from the public when gathering information on species of interest due to costly equipment, hours involved in the field, and sometimes public opposition towards methods used in capturing wildlife. However, some temporal and spatial biases may be inherent in public surveys. Respondents may provide information based primarily on daytime sightings in which encounters with wildlife may be brief, and the species being investigated may be present in habitat which may make them difficult to observe. Quinn (1995) determined sighting information in his study underestimated the use of forest habitat by coyotes, compared to telemetry data, suggesting forest cover may have shortened sighting distance. I believe that selecting local hunters to acquire sighting information in this study helped reduce these biases since many hunters establish themselves in the field at dawn, some may move to different locations during the day or hunting season, and many often remain in the field until dusk. Hence, hunters have a greater chance of encountering wildlife than the general public because they spend more time in the field, including the crepuscular hours when many carnivores are active. In addition, the average hunter is fairly knowledgeable of common wildlife through education or experience, so species identification should be accurate. It is also assumed that local hunters are familiar with the areas they hunted to be able to correctly identify and mark approximate locations on a map where carnivores were sighted, thus selecting hunters who live in the region should have provided reliable sighting data for this study. There are some limitations to this type of survey, particularly with potential marking errors. However, hunters are also skilled map readers compared to the general public and several hunt on their own property, thus the locations marked on the returned maps should be accurate. In addition, some error is expected in how the user interprets the marked location and transfers that location to its place within the GIS. However, the 1-km² (radius = 564 m) buffer reduced much potential error influence.

Species-habitat relationships are often determined by location data, and the potential for marking errors may result in assigning inaccurate habitat relationships (McKelvey and Noon 2001). This may occur whether through sighting data or using triangulation with radiotelemetry, thus a degree of spatial uncertainty exists in point placement for carnivore sightings in this study. Location data was entered in the GIS as accurately as possible by cross-referencing roads and streams on plat maps with road and stream TIGER/Line® data. Since species-habitat relationships are not being determined solely upon which land cover type the location data fall in, but through analyzing multiple metrics within 1-km² areas surrounding each location, then this may have reduced the chances of producing spurious results.

The low number of red foxes sightings was not surprising because the number of sightings from statewide Archery Deer Hunter Surveys (Bluett 2004) has been steadily declining since 1992. A possibility for the low red fox numbers is that coyote dominance may be pushing red foxes out of the area, or producing high red fox mortality rates (Bekoff and Gese 2003). Studies have determined that red foxes prefer a mosaic of land cover types, of which there are plenty of areas within the region. Therefore, this species should be investigated further. Aside from the reasons above, habitat is crucial for providing food and shelter, and the habitat relationships between the three species within the study area will be addressed later in this chapter.

The number of bobcats sighted was relatively high, which may be an indication that they continue to thrive in the region. Information from the statewide Archery Deer Hunter Survey (Bluett 2004) indicates bobcat numbers have been gradually increasing since 1992; bobcats remain a non-game species since being de-listed in 1999. Despite a 51.4% increase in the number of coyotes harvested statewide from the 2002–2003 to 2003–2004 seasons (Bluett 2004), coyotes appear to be the dominant carnivore in the region. It must be noted, though, that some individuals of all three species have likely been sighted more than once during the survey, and the number of sightings from the hunters is not an indication of population size. Thus, separate studies would need to be conducted to accurately determine the status of these species in this region.

Ecologists often perform their own land cover classification or utilize GAP data to determine species-habitat use in their studies. Two issues which are important considerations for analysis with this data are classification accuracy and scale. Jensen (1996) states three accuracy measures should be reported from classified land cover data; overall accuracy, producer's accuracy, and user's accuracy, and many studies report only one number to represent classification accuracy. Anderson et al. (1976) recommend in their classification criteria that the minimum level of classification accuracy should be 85%. The producer's and user's accuracy were not reported in the metadata for the classified land cover data used for this study; however, classification accuracy for agriculture-related land cover was determined to be between 85-95%, and land cover classes were assessed to be generally greater than 80% accurate (Illinois Natural History Survey 2003). These accuracies are similar or better than those presented in other published wildlife studies (Rolley and Warde 1985; Knick and Dyer 1997; Stoms et al. 1993; Quinn 1995). Thus, the Illinois GAP data were reliable for this study.

The smallest scale that can be used for analysis is the spatial resolution of the original satellite image, which in this case was 30 meters. The limitations with this scale is that contours and size of some land cover patches may not represented, and several land cover types may be unrepresented in the pixels after classification. This can be problematic when analyzing metrics such as edge density, patch size, and proximity to other patch types. Thus, one must consider the limitations of land cover data when making assumptions of habitat use.

Due to the 30 meter spatial resolution of Landsat TM/ETM+ imagery used for classification, streams and secondary roads were not represented well. Acquiring properly-delineated road and stream data is time-consuming and costly; therefore TIGER/Line® data were chosen for the road and stream layers to determine density of these features in this study. This may pose limitations on spatial analyses due to lower positional accuracy. However, stream density was not considered significant between any of the species, thus no species-habitat interpretations were made regarding this variable. Road density was different between red foxes and bobcats, and I believe this data set is acceptable for analysis within these boundaries based on results of this study and from other literature.

Nielsen and Woolf (2002) used the Penrose distance method for modeling bobcat habitat-relative abundance relationships, and Knick and Dyer (1997) used Mahalanobis distance, a similar statistical method, to determine black-tailed jackrabbit habitat distribution. My study incorporated the Penrose distance method to determine habitat relationships, but taking a multi-species approach for sympatric carnivores. Mapping Penrose distances was based upon assigning Penrose distance values to hexagon coverage over a 370,000-ha study area that closely matched similar Penrose values in mean habitat vectors for the species; the lowest values represent areas of highest habitat affiliation. Individual species maps indicated strong differences and some similarities in habitat affiliations, while a separate map indicated the percent difference in Penrose values showing the distribution of areas with equal or greater habitat affiliation between red foxes and bobcats.

Univariate statistical tests determined only road density and mean fractal dimension index for landscape were significantly different between coyote-red fox and coyote-bobcat pairings, respectively, and a Penrose distance model was not created for coyotes. This indicates that coyote habitat affiliation overlaps considerably with that of the red fox and bobcat. Studies have shown that home ranges, habitat use, and diet overlap in varying degrees among red foxes, coyotes, and bobcats (Major and Sherburne 1987; Dibello et al. 1990), therefore it was not surprising that there were few variables which separated coyotes from the other two species in this analysis.

Five significant variables were important between red foxes and bobcats: percentage of grassland patches, interspersion and juxtaposition of forest patches, mean fractal dimension of wetland patches, mean fractal dimension of the landscape, and road density. The percentage of grassland for species mean vectors was highest for red foxes and lowest for bobcats in the study area. While bobcats are typically associated with areas of forest habitat and dense understories (Anderson and Lovallo 2003), those in regions with a fair amount of grassland, such as in southern Illinois use this cover type. Nielsen and Woolf (2002) incorporated percentage of grassland in their bobcat habitat model, with bobcat mean vectors containing 17.4 ± 2.0 (SE) percent grassland. Kamler and Gipson (2000) determined resident bobcats in Kansas preferred grasslands in summer and woodlands in the winter. Grassland use by female bobcats in southeastern Oklahoma peaked in the winter, while grassland use by males peaked in the spring (Rolley and Warde 1985). Neale and Sacks (2001) observed bobcats using grassland less than chaparral, forest, and woodland habitats. Though the extent of grassland use by bobcats is unknown in this study, the aforementioned studies have shown bobcats use grassland cover to some degree when available. The likelihood of bobcats using grassland in southern Illinois may be greater due to the patchiness of the landscape and the amount of grassland available compared to other regions where homogeneous forests occur (Knowles 1985; Major and Sherburne 1987). In addition, bobcats may find more variety in small mammal prey items in grassland, compared to larger mammals present in forest edges or interiors.

Red foxes are typically found in more heterogeneous landscapes and open habitats relative to bobcats (Cypher 2003). Their use of grassland may vary depending on the season, prey availability, and competition by coyotes. A summer study in northwest British Columbia determined red foxes collectively used fen areas which were dominated by grasses and sedges, and individually used grass habitat as expected (Jones and Theberge 1982); intermediate densities of small mammals also occurred in the grass community. Dekker (1983) observed red foxes foraging in snow-covered fields or grassland during winter. A comparison between rural and urban red foxes showed rural foxes used human-associated habitats, particularly abandoned farmsteads, while urban foxes generally selected urban grassland and other urban developed areas (Gosselink et al. 2003). It was noted that habitat selection among rural foxes were influenced by coyote presence.

Interspersion and juxtaposition, or adjacency, of forest patches was important for both species, but highest for bobcats. Several studies have shown the predominance of forest selection by bobcat, thus it was not surprising that forest adjacency was an important variable. Witmer and deCalesta (1986) determined bobcats used open areas for nocturnal hunting and then retreated to forests during the day. Lovallo and Anderson (1996) and Kolowski and Woolf (2002) noted a seasonal shift away from unforested habitat and fields to forests in the winter. These shifts may occur due to better utilize their ambush hunting tactics (Kamler and Gipson (2000), or for changes in prey availability, reduction in competition, maintaining territories, or reproduction needs

(Rolley and Warde 1985). Red foxes have also selected forest habitat based on different factors. Major and Sherburne (1987) noted hardwood and hardwood-dominated mixed woods were selected by red fox during most seasons in their Maine study area, while softwood and softwood-dominated mixed forests were used less. Halpin and Bissonette (1988) found red fox use of hardwood stands for traveling increased during periods of crusty snow, and they used thick understory vegetation more as snow depth increased; these areas also supported prey species. In contrast, rural red foxes avoided woodlands and cover-rich habitats in general due to coyote presence (Gosselink et al. 2003). Therefore use of forested habitats by red foxes may depend on climate, availability of prey, and predator abundance.

The mean fractal dimension, or degree of complexity, of wetland patches were also important to bobcats and red foxes. Kolowski and Woolf (2002) incorporated two water variables in their final model for bobcats, which they suggested were selected areas for travel, prey habitat, and areas of rest along riparian corridors. In south-central Florida, bobcats showed a preference for marshes at the core-area level during the wet season (Thornton et al. 2004). In contrast, McCord (1974) observed that bobcats were indifferent to use of wet areas. Though most studies have not indicated a strong selection of this cover type by bobcats, the wetlands in this region may show complex edges, potentially providing additional cover for loafing or additional opportunities for seeking prey. Wetland and grassland edges contain food resources sought by red foxes (Phillips et al. 2004). Sargeant (1972) observed that red foxes avoided marshes and swamps during ice-free seasons, but used them in the winter. Red foxes primarily prey upon rodents and leporids, but also consume a variety of other food items than bobcats, including waterfowl (Cypher 2003). Another study by Sargeant (1978) estimated the prey demands of red fox adults and pups during the pup-rearing period, and a larger percent of ducks were consumed compared to jackrabbits; prey remains left by the pups were similar to those at natural dens. He suggested that a small percentage of ducks in the red foxes' diet could affect particular waterfowl populations. It may be possible that red foxes seek wintering waterfowl as prey in wetlands within the study area.

The mean fractal dimension of the landscape represents the complexity and pattern of all patches within the area of concern. With a more complex landscape, one may assume that the amount of edge within the landscape is also higher. Edge effects have been determined to negatively affect bird species which may require more homogeneous forested landscapes (Friesen et al. 1999; Flaspohler et al. 2001). Heske (1995) suggested that fragmented landscapes produce more complex edges that produce greater diversity in food and cover for small mammals and furbearers. That appears to be the case with red foxes and bobcats in other studies, as variety in food and cover resources has allowed them to co-exist in areas that overlap with predators and adjust to seasonal changes (Dibello et al. 1990; Litvaitis and Harrison 1989; Major and Sherburne 1987).

Road densities were lower in bobcat mean vectors than in red fox vectors. For bobcats, McCord (1974) determined roads were one of the top four cover types (of 13) with highest selection index values. These were apparently used to reduce the effort of moving in deeper snow, and to move between more desirable cover types. A study by Lovallo and Anderson (1996) showed trail density was greater within bobcat home ranges, while secondary highways were lower; the densities of paved and unpaved roads were similar. They suggested use of these roads were based on vehicle traffic levels and the habitat within buffer zones around these roads. Nielsen and Woolf (2002) determined high road densities in southern Illinois resulted in high vehicle-related bobcat mortality rates. Red foxes have shown to inhabit diverse habitats, and can thrive in or near some urban areas containing relatively high road densities (Cypher 2003). Dekker (1983) noted red foxes occur primarily near human habitation and roads in central Alberta. Sargeant et al. (1987) also observed several foxes living near well-traveled roads and farmsteads, which may have occurred to avoid interspecific competition with coyotes. Location data from this study suggests there is an abundance of coyotes in the region, thus red foxes may be utilizing several farmsteads and ex-urban areas to avoid coyotes, thereby increasing the road density within their areas used.

The red fox Penrose model indicates a strong preference for grassland ($r = -0.51$) and areas with a heterogeneous mix of land cover. This was apparent in early statistical analyses, in which the means for three significant grassland metrics (PLAND, AREA_MN, and CORE_MN) were highest for red foxes. Cypher (2003) also describes red fox habitat as being highly fragmented with variation in land cover. Road density was also higher for red foxes, which is understandable since red foxes are associated more with urban areas compared to bobcats. This may also be supported by the number red fox sightings (11% of total carnivore sightings) compared to bobcats (39% of total carnivore sightings). Despite a smaller sample of red foxes, more roads were within 1 km^2 of their locations. Though the Penrose map shows red foxes avoiding the larger urban areas, hexagons with low Penrose values are shown around the outskirts of these locations, which may be considered ex-urban landscapes. Therefore, road density in these locations would still contain a fair amount of roads compared to more rural, forested areas associated with bobcats. The bobcat Penrose model indicates more of a preference for forest habitat over red foxes ($r = -0.37$), and less affiliation with highly fragmented landscapes mixed with grassland, agriculture, and forest. These highly fragmented areas do not provide heavy understory which are important for bobcats to stalk or ambush prey (Anderson and Lovallo 2003). Similar to red foxes, the map also indicates high avoidance of large urban areas and homogeneous agricultural areas.

The Penrose map showing percent differences between Penrose values for red foxes and bobcats is the strongest map for indicating areas of greatest species-habitat affiliations, distribution of these habitats, and areas with the least overlap in habitat affiliation. The break points used to separate ranges of values were 25%, 50%, 75%, and >75%. I combined all Penrose difference values falling within the 0-25% range for both red fox and bobcat since values below 25% difference do not necessarily indicate significantly higher affiliations. The 0-25% range indicated that both species avoided large urban areas and large homogeneous agricultural areas. Thus, agricultural and urban areas are where there is greatest overlap in models between red foxes and bobcats. These low affiliations are most likely due to lack of abundant food resources and cover, and high human activity. Though red foxes may utilize or inhabit urban landscapes comparatively more than bobcats due to their more generalist diet and adaptability to human interaction (Anderson and Lovallo 2003; Cypher 2003), they probably lack strong affiliations with those environments unless there are extrinsic pressures involved, such as strong coyote presence.

5.2 Conclusion

The habitat models created for red foxes and bobcats appear to be accurate, and both were validated with 64% of the red fox points and 65% of the bobcat points falling in the top 50% of Penrose distance values. These models give a good indication of habitat use for the study area, but they are not comprehensive; that is, they do not show other underlying factors that may drive animals to use certain habitats. It was recognized earlier that coyote-habitat affiliations were similar to those of both red foxes and bobcats, therefore it is not possible to draw inferences about the possible effects the regional coyote population may have habitat use by either species. The number of coyote sightings, however, may indicate a strong presence in the region which can affect red fox numbers. Home ranges for individuals in the study area are unknown, which if acquired could give a clearer understanding of how interactions among these species affect habitat partitioning. There may be differences in habitat use based on a species sex and age, prey densities, temporal partitioning, and the seasons (Litvaitis and Harrison 1989; Neale et al. 2001; Gosselink et al. 2003). For example, the amount of snowfall and mean temperatures for Carbondale in November and December were 0.0 cm/10.3°C (Nov.) and 33.0 cm/1.1°C (Dec.) in 2004, and 0.0 cm/9.9°C (Nov.) and 5.1 cm/0.8°C (Dec.) in 2005, respectively (Illinois State Water Survey 2006). Because southern Illinois did not receive extreme winter weather during the survey periods, it is possible habitat use might be slightly different in this region compared to other regions where large differences in climate occur; partitioning of habitat due to the amount of snowfall and prey abundance in those regions may be important.

The relationships between sympatric carnivores in this area should be explored further to better understand causal effects of habitat use. However, some species-habitat relationships for red foxes and bobcats found in this study are similar to those cited in previous studies with similar landscapes and cover types. Based on the results of the individual species models and Penrose percent difference model, there were significant differences in habitat affiliations between red foxes and bobcats. Though coyotes were not represented, they may prefer habitat used by both species, perhaps areas of grassland that are adjacent to forested habitat where they can work the edges while foraging and seek cover during the day. According to the Penrose differences map, the distribution of most favorable habitat for red foxes appears to be in the eastern areas of Union and Williamson Counties with a narrow northwest to southeast range in Jackson County. The distribution of favorable habitat for bobcats is primarily the north-to-south range of the Shawnee National Forest in Jackson and Union Counties, and a narrow stretch of wetlands along the northern parts of Jackson and Williamson Counties. This study provides insight into habitat partitioning and overlap among sympatric carnivores, and these maps may be useful in determining locations for future study areas in the region.

Finally, there are also benefits to the sighting data and modeling technique used in this study. The collection of sighting data from experienced hunters is simple and cost-effective, and a hunter database should be easy to acquire from most state wildlife agencies. Sighting data from hunters are also valid due to their knowledge of wildlife and hunting locations. The advantages of using the Penrose distance model are that it works well for presence data, and it may be potentially useful for the conservation of several species.

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APPENDICES

APPENDIX A: 2004 Hunter Survey Cover Letter

Southern
Illinois University
Carbondale

6 April 2005

Illinois Deer Hunter:

I am a graduate student seeking a Master's degree in the Department of Geography and Environmental Resources at Southern Illinois University Carbondale. This research is supported by the Cooperative Wildlife Research Laboratory.

The purpose of the enclosed survey is to gather information on red fox, gray fox, coyote, and bobcat locations in the Illinois counties of Jackson, Union, and Williamson. You were selected to participate in this study because of your sighting of one or more of these carnivores during the Illinois 2004 deer firearm hunting season.

Please take a moment to indicate on the enclosed map with a dark solid dot the approximate location of each carnivore sighted during that season, and write the species observed.

Completion and return of this survey is voluntary. If you are under 18 years of age do not respond to this survey. Please use the postage paid return envelope provided.

Questions about this study can be directed to me or to my supervising professor, Dr. Clay Nielsen, Cooperative Wildlife Research Laboratory, SIUC, Carbondale, IL 62901-6504. Phone (618) 453-6930.

Thank you for taking the time to assist me in this research.

Sincerely,

Patrick McDonald
(618) 453-6453

This project has been reviewed and approved by the SIUC Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research Development and Administration, SIUC, Carbondale, IL 62901-4709. Phone (618) 453-4533. E-mail siuhsc@siu.edu

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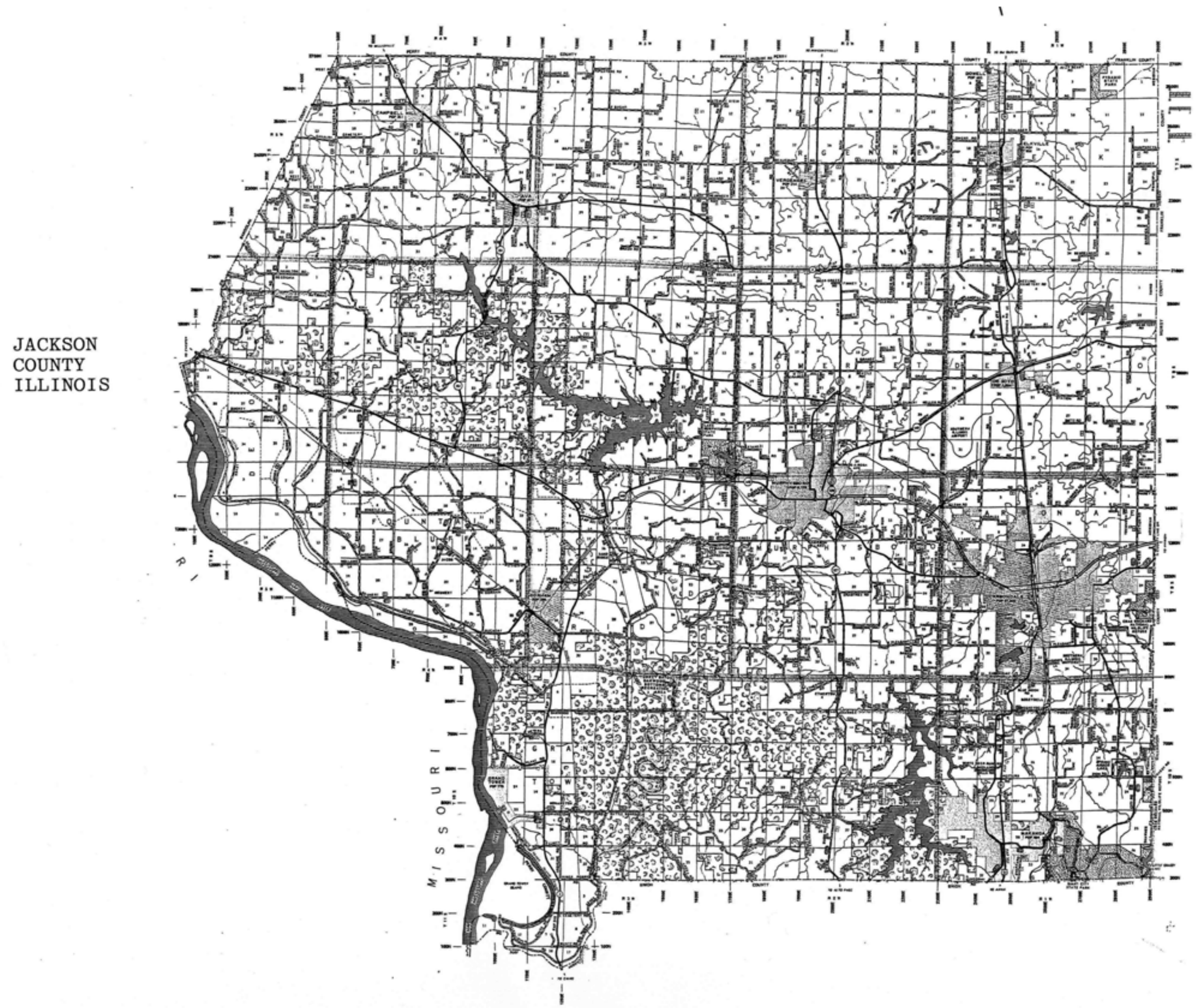
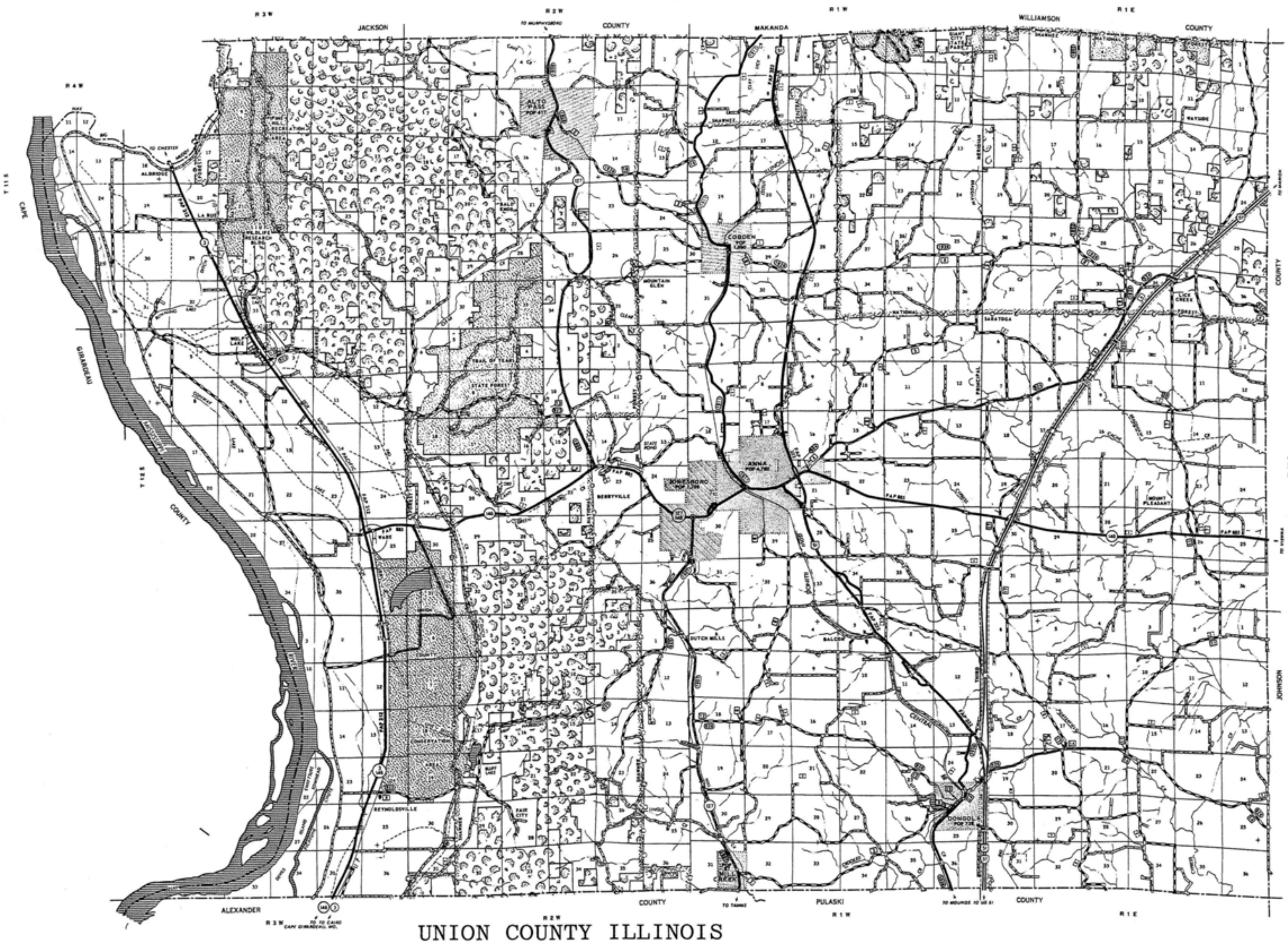
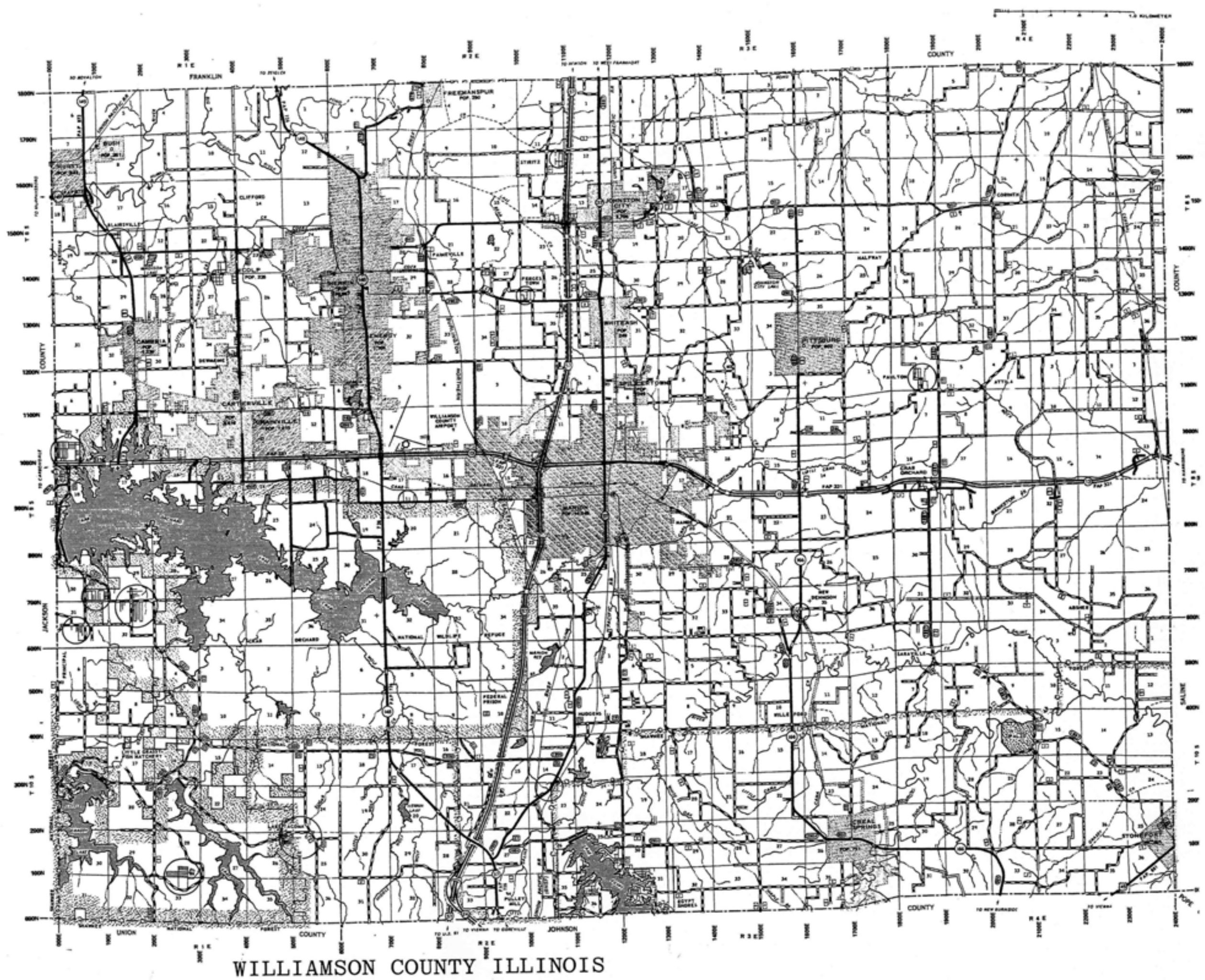
APPENDIX B: Jackson County, IL Plat Map



APPENDIX C: Union County, IL Plat Map



APPENDIX D: Williamson County, IL Plat Map



APPENDIX E: Survey Postcard

Dear Illinois Deer Hunter,

A Carnivore Sighting Survey was recently mailed to you. **If you have returned this survey, we thank you. If not, please take a moment to complete it as soon as possible. This survey is voluntary, but your input is valuable!** If you did not receive a survey, or if it was misplaced, please call and we will send you another immediately. If you are under 18 years of age do not respond to this survey. Phone (618) 453-6094.

Thank you for your cooperation.

Patrick T. McDonald
Graduate Student
Department of Geography and Environmental Resources
Southern Illinois University Carbondale

APPENDIX F: 2005 Hunter Survey Cover Letter

Southern Illinois University Carbondale

5 December 2005

Dear Illinois Deer Hunter,

I am a graduate student seeking a Master's degree in the Department of Geography and Environmental Resources at Southern Illinois University Carbondale. This research is supported by the Cooperative Wildlife Research Laboratory.

The purpose of the enclosed survey is to gather information on red fox, gray fox, coyote, and bobcat locations in the Illinois counties of Jackson, Union, and Williamson. You were selected to participate in this study because of your sighting of one or more of these carnivores during the Illinois 2004 deer firearm hunting season. As the method of reporting deer harvest has changed for the 2005 firearm hunting season in these three counties, I am relying on hunter contacts from last year. Enclosed is a map of the county you hunted in last year.

Please take a moment to indicate on the enclosed map with a dark solid dot the approximate location of each carnivore sighted during the Illinois 2005 deer firearm season, and write the species observed for each dot.

Completion and return of this survey is voluntary. If you hunted only in one of the other counties listed above, let me know and I will send the appropriate map. If you are under 18 years of age do not respond to this survey. Please use the return envelope provided.

Questions about this study can be directed to me or to my supervising professor, Dr. Clay Nielsen, Cooperative Wildlife Research Laboratory, SIUC, Carbondale, IL 62901-6504. Phone (618) 453-6930.

Thank you for taking the time to assist me in this research.

Patrick McDonald
(618) 453-6094

This project has been reviewed and approved by the SIUC Human Subjects Committee. Questions concerning your rights as a participant in this research may be addressed to the Committee Chairperson, Office of Research Development and Administration, SIUC, Carbondale, IL 62901-4709. Phone (618) 453-4533. E-mail siuhsc@siu.edu

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VITA

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Habitat Affiliations of Sympatric Carnivores in Southern Illinois

Major Professor: Dr. Tonny J. Oyana

Publications:

Frazier, J.A., P.T. McDonald, and K.J. Regester. 2004. Geographic Distribution: *Rana clamitans*. *Herpetological Review* 35(4):406.

McDonald, P.T., J.A. Frazier, and K.J. Regester. 2004. Geographic Distribution: *Notophthalmus viridescens*. *Herpetological Review* 35(4):403.

Regester, K.J., P.T. McDonald, and J.A. Frazier. 2004. Geographic Distribution: *Ambystoma maculatum*. *Herpetological Review* 35(4):402.