Landscape fragmentation and connectivity for carnivores in the Upper San Pedro Basin

Looking across the San Pedro River to the Huachuca Mountains *Photo courtesy of Fort Huachuca Wildlife Office*

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Funded by The Nature Conservancy and
The Fort Huachuca Wildlife Office

March 5, 2001

Suggested citation: Hass, C.C. 2000. Landscape fragmentation and connectivity for carnivores in the Upper San Pedro Basin. Fort Huachuca Wildlife Office, Fort Huachuca, AZ.

Chapter 1: Introduction

Landscape fragmentation and the importance of corridors

Landscape fragmentation, the reduction of native habitats into smaller and more isolated parcels, is one of the leading causes of wildlife endangerment today (Soulé, 1991; Noss, 1990). Agriculture, urbanization, mining, and desertification all cause significant losses in the habitat necessary to sustain long-term viable populations of organisms. Early habitat preservation efforts focused on preserving biologically rich or unique tracts of land ("hot spots"). More currently, an emphasis is placed on preserving and restoring the functionality of ecosystems by identifying, preserving and restoring important community components and processes necessary to maintain ecosystems (Harris and Atkins, 1991; Noss, 1990; Poiani et al., 2000).

Key to the latter strategy is defining the scale of concern, determining the functionality of the system, and identifying key components and processes. One key component of many ecosystems that has received considerable attention lately is connectivity (Harris and Atkins, 1991; Hoctor et al., 2000). Isolated populations, of all taxa, are vulnerable to stochastic events and the deleterious effects of inbreeding (Frankham, 1996; Soulé, 1991). In addition, some animals need huge tracts of land to fulfill forage and shelter needs, find mates, and participate in social interactions (Bennett, 1991; Rosenberg et al., 1997). Recognizing the hazards that accompany population isolation, numerous government agencies and private conservation groups have sought to reduce population isolation through the identification, preservation, and restoration of wildlife movement corridors and landscape linkages. Although sometimes used interchangeably, here I follow Csuti (1991) and Soulé (1991) in differentiating the terms:

> "A **conservation corridor** is a linear landscape feature that facilitates the biologically effective transport of animals between larger patches of habitat dedicated to conservation functions…A corridor is a *transitional* habitat; it need only provide those ecological services and resources required when individuals are moving between patches." (Soulé, 1991: 91-92).
>
> "A **landscape linkage** differs from a movement corridor in that the complex range of community and ecosystem processes continues to operate within it through time, thus enabling plants and smaller animals to move between larger landscapes over a period of generations." (Csuti, 1991: 83-84).

Obviously, the difference between a landscape linkage and movement corridor is one of scale. A highway underpass, complete with fencing to funnel animals through it, may function as a corridor for Florida panther, bobcat, and white-tailed deer (Foster and Humphrey, 1995), but may act as a landscape linkage for plants, small mammals and reptiles.

The idea of movement corridors has its detractors, with concern that such corridors may foster the spread of pathogens and exotic species, and that resources devoted to identification and preservation (or restoration) of corridors may be better used for other conservation efforts (Hobbs, 1992; Mann and Plummer, 1995; Simberloff et al., 1992). Two major problems with movement corridors are defining what constitutes a corridor, and determining if what appears to be a corridor actually functions as one (Harris and Atkins, 1991; Hobbs, 1992; Rosenberg et al., 1997).

Serious detractors aside, there is a general agreement that corridors can theoretically reduce landscape fragmentation by allowing movement (at some ecological scale) between fragments (Beier and Noss, 1998; Csuti, 1991; Harris and Atkins, 1991; Merriam and Catterall, 1991). However, what constitutes a corridor, in terms of width, length, and structure, remains unresolved (Beier and Noss, 1998; Friend, 1991; Rosenberg et al., 1997; Saunders and Hobbs, 1991). Numerous attempts have been made recently to identify potential corridors or landscape linkages using Geographic Information Systems (GIS), habitat models, and, in some cases, detailed knowledge of species life history (Brooker et al, 1999; Norton and Nix, 1991; Pace, 1991; Sorrell, 1999; The Conservation Fund, 1998; Walker and Craighead, 1997).

Previous studies have documented the presence of animals in corridors, which has been taken as an indication of their efficacy for animal movement (Bennett, 1990; Downes et al., 1997; Shkedy and Saltz, 2000). However, presence of an animal within a suspected corridor does not necessarily indicate that the corridor is being used for movement, or that the movement is successful (Rosenberg et al., 1997). Actually testing the efficacy of corridors is a formidable task, due to the necessity for large landscape areas and suitable experimental designs to reduce the problems of lack of independence, confounding variables, and the need for replicates (Inglis and Underwood; 1992; Nicholls and Margules, 1991). It is one thing to test the effectiveness of corridors of various widths and lengths for small mammals (Andreassen et al, 1996), for which corridors will seldom be designed (Soulé, 1991); but to design similar experiments for a puma or even a bobcat is beyond practical limits. Beier and Noss (1998) suggest using demographic parameters to compare untreated and treated (potential corridor removed) areas, before and after the corridor is removed. They, and Saunders and Hobbs (1991), suggest that more studies of actual dispersal of individuals will provide much needed information on actual corridor use and the types of animals dispersing. Only a few such studies have been published to date (e.g., Beier, 1993; Brooker et al., 1999).

As previously mentioned, what constitutes a movement corridor for one species may constitute a year-round habitat within a landscape linkage for another. The design and preservation of movement corridors needs to take into account the dispersal capabilities of the species of interest (Beier and Noss, 1998; Harrison, 1992; Rosenberg et al., 1997; Soulé, 1991; Van Vuren, 1998). This includes both the speed at which it can move through the corridor (which is influenced by corridor length) and the animals' sensitivity to habitat type (which may be influenced by corridor width). Width is an important factor due to the recognized effects of edges (Andren and Anglestrom, 1988; Friend, 1991; Oehler and Litvaitis, 1996; Yahner, 1988). Edge effects may permeate far into a corridor; indeed the entire corridor may be composed of edge habitat (Bueno et al., 1995). Rosenberg et al. (1997) point out that "…many edge species have high birth and survival rates in disturbed areas, and providing habitat for these species will not maintain regional biodiversity" (p. 684). Less attention has been paid to corridor length, but it is generally recognized that the shorter the better (Lindenmayer and Nix, 1993; Newmark, 1993; Soulé, 1991).

For birds, Merriam and Caterall (1991) suggested corridors may need to be > 500 m wide, to minimize edge effects. Harrison (1992) proposed that corridor width should be based on average home range size (in effect, a landscape linkage); circa 2.5 km wide for bobcats, up to 5 km wide for pumas. In linking wilderness areas in Oregon, Pace (1991) suggested corridors up to 400 m wide along streams, and up to 6 km wide along ridges. Closer to home, Harris Environmental Group (1997) suggested a 100 m corridor with an additional 100 m buffer to accommodate mule deer movements between the Tucson Mountains and Desert Biological Laboratory.

Effects of roads

Roads have major impacts on wildlife demographics and movements (Bennett, 1991; Forman, 2000; Noss, 1995; Trombulak and Frissell, 2000). Direct effects include road kill (estimates of up to 1 million animals killed each day – Noss (1995)), mortality from road construction, changes in animal behavior, loss of habitat, air, soil, and water pollution, spread of exotic and native species, and changes in aquatic regimes (Bennett, 1991; Brody and Pelton, 1989; Forman, 2000; Noss, 1995; Trombulak and Frissell, 2000). Indirect effects include increased human access into areas, which further exacerbates the effects of the roads themselves (Noss, 1995). In some habitats, roadside vegetation may act as landscape linkages for small mammals and birds (Bennett, 1991), but, in general, roads have detrimental effects on large mammals, through road kill and avoidance behavior that effectively fragments populations (Brody and Pelton, 1989; Noss, 1995; Trombulak and Frissell, 2000). Underpasses and overpasses facilitate movement through this barrier, but their efficacy depends on structure, landscape features, and human activity, with different species responding to these variables differently (Clevenger and Waltho, 2000; Foster and Humphrey, 1995). Roads, therefore, need to be considered as a factor when examining landscape fragmentation and corridor design.

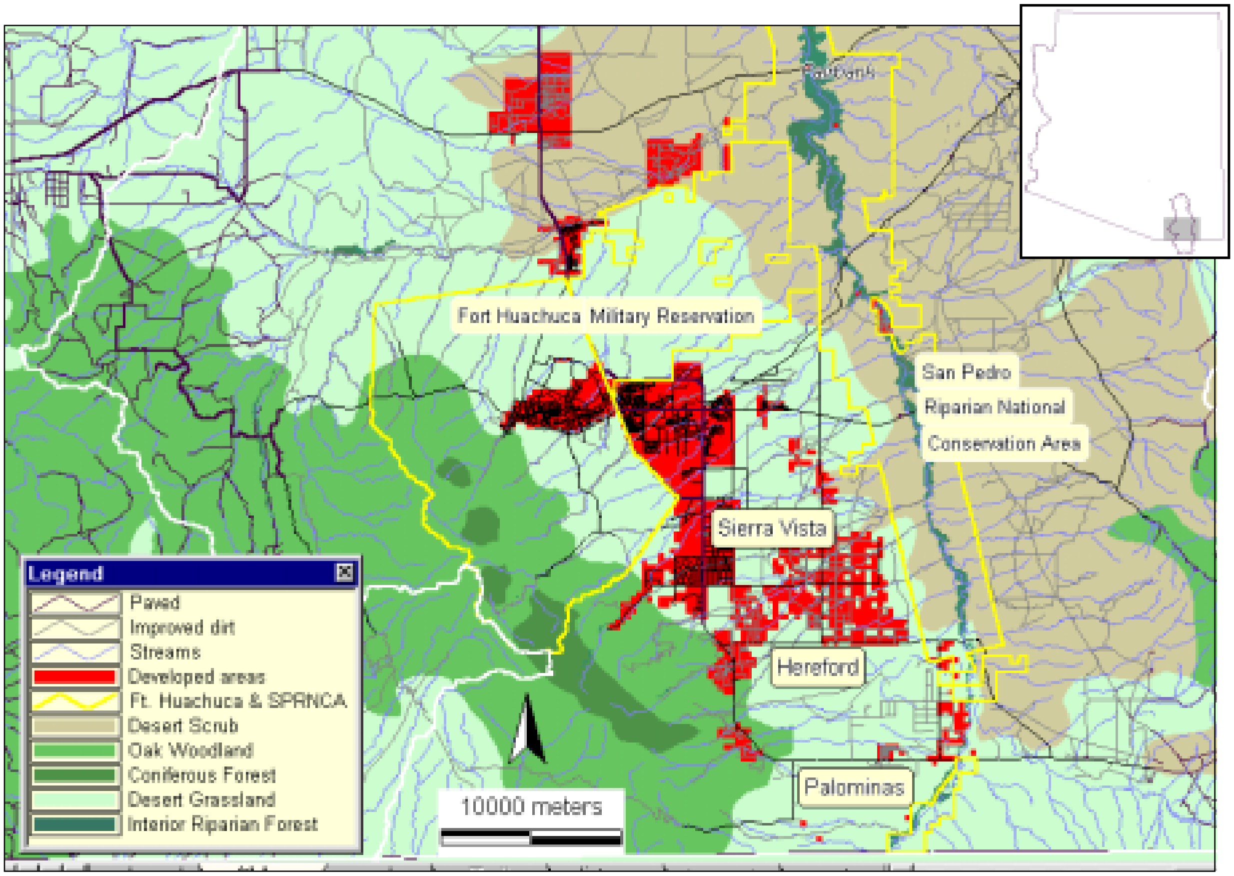
The Upper San Pedro River Basin

The San Pedro River represents one of the last free-flowing rivers in the southwest, as it makes its way from its headwaters near Cananea, Sonora, 240 km (145 miles) north to its junction with the Gila River near Winkleman, Arizona. It flows through an area called the Madrean archipelago, with forested mountains ("sky islands") surrounded by grasslands. The Upper San Pedro River basin extends from its headwaters 37 km south of the Mexican boundary to the narrows, 19 km north of Benson, Arizona (Bureau of Land Management, 1998). The upper basin is bounded by Sierras San José, Los Ajos, and La Mariquita in Mexico, and in Arizona, by the Mule and Dragoon Mountains to the east and the Huachuca, Mustang, and Whetstone Mountains to the west.

The San Pedro River Valley has felt the impact of humans for > 10,000 years. Prehistoric Clovis points associated with remains of mammoths have been found not far from the River's banks (MacGregor, 1974). Hohokam, Sobaipuri, and Apache occupied the area at various times (Hastings and Turner, 1980). The Sobaipuri (Piman) cultivated maize in the valley > 4,000 years ago (Altschul, 1997; Vanderpot, 1997). During 1540, Francisco Vasquez de Coronado led an expedition north along the San Pedro searching for the seven cities of gold. They encountered the agricultural fields of the Sobaipuri, irrigated by an extensive network of canals from the San Pedro (Dobyns, 1994). During the 1820s, large-scale Mexican cattle ranching began in the area. By the mid-1800s, the character of the San Pedro River began to change, with mesquite bosques, cienegas, and lush grassland replaced by steep arroyos, narrow cottonwood-willow forests, and replacement of native grasses with non-natives (Hastings and Turner, 1980). The United States acquired the territory from Mexico during 1854; shortly thereafter, the U.S. Army established installations in the area to protect settlers from raids by Apaches (Hastings and Turner, 1980; Wilson, 1995). Removal of Apaches from the area by 1886 opened it up for large-scale settlement including extensive cattle ranching, farming, logging, and mining (Hastings and Turner, 1980; Dobyns, 1994; Wilson, 1995). Changes also occurred in the surrounding mountains. Grazing, mining, timber cutting, fire suppression, market hunting, and overzealous predator control have changed the composition of the forests and wildlife within (Wilson, 1995).

Rapid urbanization is presently occurring between the foot of the Huachuca Mountains and the lush riparian corridor associated with the San Pedro River. Sierra Vista, the largest municipality in the area, has experienced a considerable growth rate in recent years. The amount of urban area increased by > 400% between 1973 and 1997, at the expense of grassland and desert scrub (Kepner et al., 1999). For the period 2000-2040, the overall expected growth for the region is ≥ 15% (Southeastern Arizona Government Organizations, 1995). The Sierra Vista-Huachuca City area is expected to see most of the growth. The rapid subdivision of former cattle ranches now threatens to sever potential wildlife corridors between the San Pedro River and the Huachuca Mountains (Fig. 1.1).

Currently, management of the Upper San Pedro River basin in the United States is the responsibility of the Bureau of Land Management, private landholders, and Arizona Department of Lands (state trust lands). During 1988, the San Pedro Riparian National Conservation Area (Bureau of Land Management) was established to protect the natural and cultural resources along a 50-km stretch near the Mexican border. The Arizona Chapter of The Nature Conservancy established the Upper San Pedro Ecosystem Program in 1996 to broaden the scope of conservation efforts in the area, and to address landscape-scale conservation issues in the larger Huachuca Mountain ecosystem, and the nearby San Pedro River.



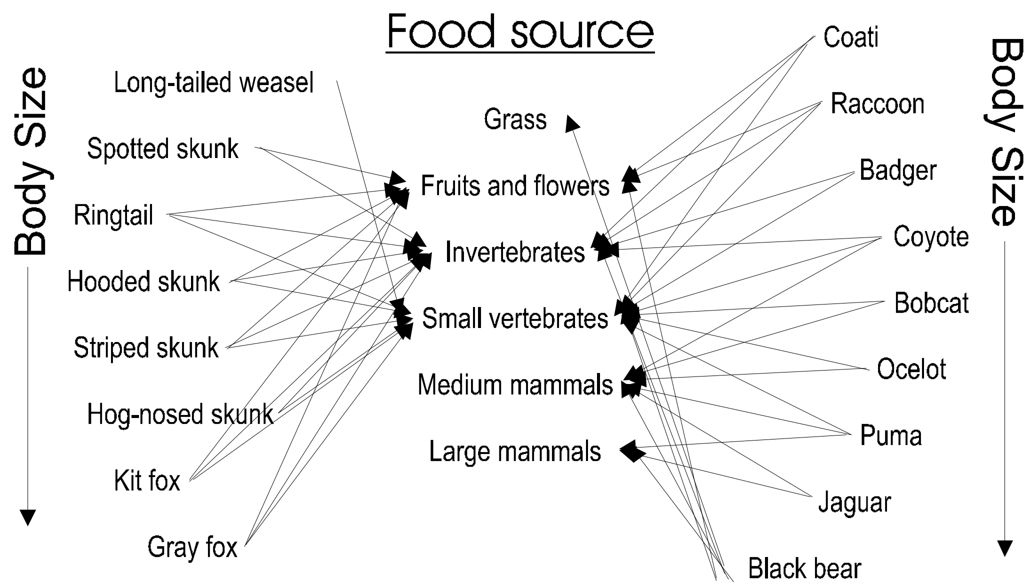
• Figure 1.1. Location of study area. Inset shows location of the upper San Pedro River basin.

The Huachuca Mountains flank the western side of the Upper San Pedro basin just north of the Mexican border. Rising to 9,445 feet at Miller Peak, and encompassing approximately 100 mi^2, the northward and eastward drainages are within the San Pedro River basin. Vegetation types in the mountains include Madrean evergreen forest and woodland, montane conifer forest, with riparian deciduous forest lining wetter stream courses, and plains and desert grasslands at lower elevations (Shaw, 1999). Management of lands within the Huachuca Mountains is primarily by the U.S. Forest Service (Coronado National Forest), the Department of Defense (Fort Huachuca), and the National Park Service (Coronado National Memorial). Additional landowners include The Nature Conservancy, Bureau of Land Management, Arizona State Lands Department, and private landowners. Some of the development of Sierra Vista and surrounding communities has been within the foothills of the Huachuca Mountains.

Despite all of the changes along the San Pedro River and surrounding mountains, it remains one of the most biologically diverse areas of the United States (Simpson, 1964). The San Pedro River acts as a biological link among the Sierra Madre, Rocky Mountains, and Sonoran and Chihuahuan deserts. It contains floristic and faunal components of all four ecosystems. The San Pedro River and surrounding mountains were once the home of the Mexican grizzly, Mexican wolf, jaguar, and ocelot. Carnivores currently found in the area include three species of procyonids (raccoons, coatis, and ringtails), four species of mephitids (hooded skunks, hog-nosed skunks, spotted skunks, and striped skunks), two species of mustelids (badgers, and long-tailed weasels), three species of canids (coyotes, gray foxes, and kit foxes), two cats (bobcat and puma), and one bear (black bear; Hoffmeister and Goodpastor, 1954; Hoffmeister, 1986).

It could be argued that none of the 15 species of carnivores above is a keystone species (Mills et al., 1993; Paine, 1995; Power et al., 1996). However, the variety of habitats they occupy and range of foods they consume suggest that their presence is an indication of ecological integrity (Fig. 1.2). Many of these carnivores are near the northern extent of their range (e.g., coatis, hooded skunks, hog-nosed skunks, plus the Mexican grizzly, Mexican wolf, jaguar, and ocelot). The San Pedro River may represent an important conduit for genetic exchange between source populations in Mexico and populations north of the border. The forested expanses of the sky islands may also serve this function. Animals normally found in the forested areas of the sky islands may use the San Pedro River as an oasis while dispersing between isolated forests. For animals whose large home ranges may extend between two or more mountain ranges, this oasis may represent a critical movement corridor between portions of their home ranges, or while looking for mates. Other animals with wider ecological tolerances, such as gray fox and bobcat, may not only use the river as a dispersal corridor, but may be long-term residents of the surrounding riparian forests and grasslands. Retention of linkages between the river and surrounding mountains may be critical for genetic exchange over a long time scale.

• Figure 1.2. Food habits of carnivores possibly present in the Upper San Pedro River basin.



Detailed measurement of animals' use of landscape usually requires radio telemetry, which can be very expensive and time-consuming (White and Garrott, 1990). Viable alternatives are track and sign counts, which can be done at a much lower expenditure of time and money (Kutilek et al., 1983; Linnell et al., 1998; Schaller and Crawshaw, 1980; Stander et al., 1997; Thompson et al., 1989; Van Dyke et al., 1986; Wemmer et al., 1996; Zielinski and Kucera, 1995). This study used track and sign counts to detect use of different landscape features by a diverse group of carnivores inhabiting the Upper San Pedro Ecosystem, including the Huachuca Mountains and the San Pedro Riparian National Conservation Area. Carnivores, as a group, are ideal for this type of study. They occupy a wide range of habitats, consume a variety of foods, and some require huge expanses of territory to survive.

Objectives

The objectives of this study were twofold. The first objective, documented in Chapter 2, was to use track surveys to inventory the San Pedro Riparian National Conservation Area and Fort Huachuca for carnivore presence and diversity, and identify habitat components that different carnivores appear to use for travel. The second objective, described in Chapter 3, was to take the results of the tracking study, and using the pattern of development in Sierra Vista and surrounding communities, identify what areas may be suitable for wildlife movement corridors or landscape linkages.

Chapter 2: The tracking study

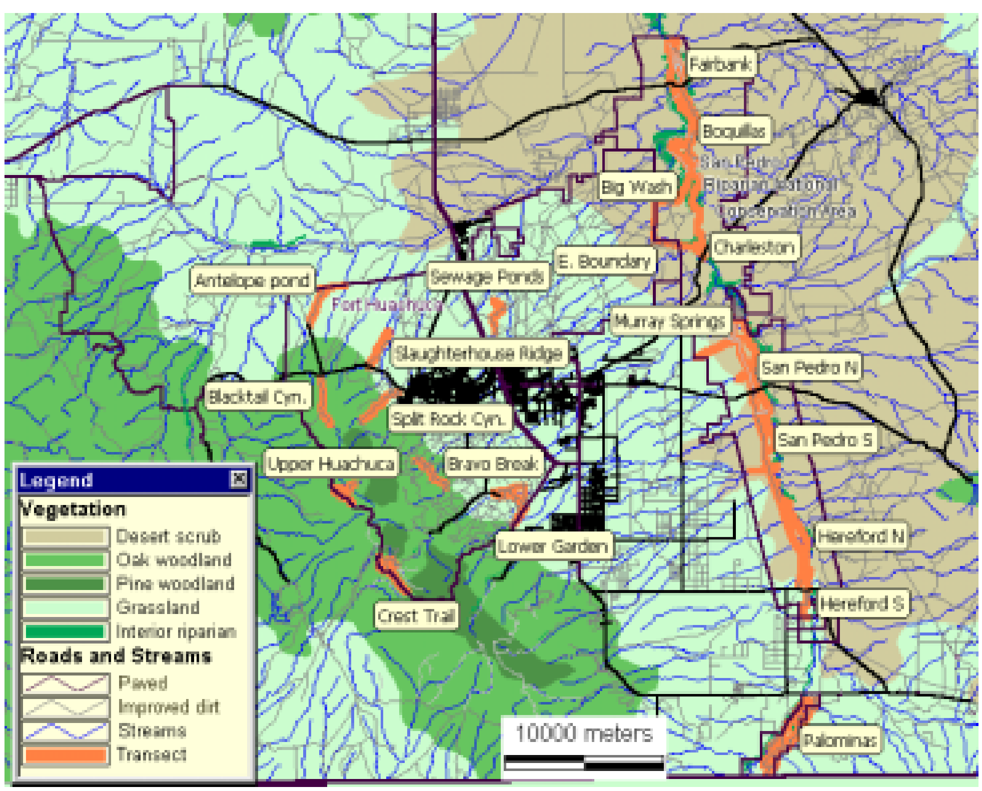
Methods

Tracking Routes

Tracking routes were established at two sites: Fort Huachuca Military Reservation and the San Pedro Riparian National Conservation Area. Ten routes were established at each site. Fort Huachuca was chosen because it includes an extensive portion of the Huachuca Mountains and tributaries that drain into the mainstem of the San Pedro River. It also includes a large network of dirt roads, firebreaks, and trails that provide good tracking surfaces that traverse and intersect ridges and washes. Routes on Fort Huachuca were selected to include woodland (5 routes, 16 km) and grassland/scrub (5 routes; 21 km). Routes included ridges, washes, and flats, and ranged from 2.6 to 6.7 km long (Fig. 2.1). Transects were not chosen randomly, but were subjectively located based on trackable surfaces and proximity to certain landscape features.

With the exception of state and county roads that cross the San Pedro River and a couple of dirt roads used for administrative purposes, most of the NCA is closed to motorized vehicles. However, the NCA includes an extensive set of trails and abandoned dirt roads that parallel the riverbed. Ten routes were chosen within the NCA that encompassed most of the river from Willow Wash (north of Fairbank) to the Mexican border (Fig. 2.1). Most routes consisted of loops that included a road or trail in the scrub/grassland next to the river and a return route within the riparian gallery of the riverbed. Routes ranged from 1.9 to 11.8 km long. Each route was surveyed at least three times between October 1998 and January 2000; four routes were surveyed four times. At least 2 months separated surveys on any individual route. Surveys were conducted at least 2 weeks after any precipitation, except for three routes on Fort Huachuca that were conducted after fresh snowfalls.

- Figure 2.1. Locations of tracking routes on Fort Huachuca and the San Pedro Riparian National Conservation Area.



Sign Identification and habitat variables

Field cards were developed that included details of track structure and measurements from published sources (Aranda, 1981; Halfpenney, 1986; Murie, 1975; Orloff et al., 1993; Rezendes, 1992), and foot measurements from live-trapped and road-killed animals. As routes were surveyed, each time sign was encountered, it was identified to genus (hooded or striped skunks) or species (everything else). The location was determined using a Garmin® 45 GPS receiver in conjunction with a USGS 7.5 minute topographic map. During each survey, data were recorded for the sign location only if it was > 1 km from previously recorded sign for that species, or it was in a different habitat type. Topography (ridge, wash, side hill, flat) and vegetation type (grassland, desert scrub, oak-pine woodland, riparian forest)[1] within a 10-m circle were recorded. The distance to the nearest source of water was estimated categorically (< 10 m, 11-20 m, 21-50 m, > 50 m). Whether the animal was following or crossing the path was recorded, if it could be determined. During surveys conducted from October 1998 to March 1999, distance to the nearest wash (< 10 m, 11-20 m, 21-50 m, > 50m) and percent canopy cover > 3 m high within a 10 m circle (< 25%, 26-50%, 51-75%, 76-100%) were estimated ocularly and recorded. These latter two variables were replaced during surveys conducted from May 1999 though January 2000 by variables for path width (1-3m, 4-6 m, 7-9 m, ≥ 10 m) and the location in the path (center or side). These latter variables replaced percent canopy cover because I thought they might better reflect how animals use paths of various widths. The path was the area available for movement, bordered by vegetation or stream banks. A path could be a trail, dirt road, or wash.

Measurements were taken of puma and black bear tracks to differentiate among some individuals. For puma, the width of the rear plantar pad was measured within the track (minimum outline measurement, Fjelline and Mansfield (1989)); for bears the width of the metacarpal pad was measured. Whenever possible, multiple measurements were taken from a track set (continuous line of tracks) and the mode recorded. For pumas, measurements of tracks within a track set usually fell within a 3 mm range. Following Fjelline and Mansfield (1989), rear plantar pad measurements of ≥ 50 mm were considered to be from an adult male; measurement of 39-50 mm were considered from adult females or subadult males.

Data Analysis

Variation among categories was tested using log-likelihood ratio tests (Sokal and Rohlf, 1981). For topography, vegetation types, and travel surfaces, expected values were calculated using a GIS to determine the km of route within each category. Expected values for other categorical variables were calculated by dividing the number of sign units by the number of categories. Experiment-wise error rate was balanced against statistical power by using an α of 0.05 (Sokal and Rohlf, 1981; Bart et al., 1998), however, exact p-values (to 4 digits) are also reported.

The relationship of urbanization to the track surveys was examined by calculating two indices of urbanization. For urban code, a 1:50,000 topographic map of the area produced by the Defense Mapping Agency in 1994 was used to classify the number of dwellings within a 5 km radius circle to the center of the transect as low (<2 houses/km^2), moderate (3-10 houses/km^2) or high (>10 houses/km^2). Routes were also classified as moderate or high if they were within 5 km of a busy highway or congested area such as an airport. The second index was an estimate of the distance from the center of the transect to the nearest occupied buildings.

Carnivore diversity was calculated for each route as the number of total carnivore species for which sign was detected divided by the total number of kilometers covered for that transect during the study. Analysis of Variance was used to test carnivore diversity by habitat type, urbanization and distance to the Mexican border.

[1] Vegetation type was classified according to the predominant type within a 10-m circle surrounding the track. Riparian forest included cottonwood/willow/ash gallery forests > 5 m high. Mesquite bosques were categorized as desert scrub.

Spatial analyses were conducted using Manifold® Geographic Information System (CDA International, 1999), using layers for hydrology and roads from USGS, and vegetation (classification according to Brown, Lowe, and Pase (1974)) and land ownership from Arizona State Lands Department.

Results

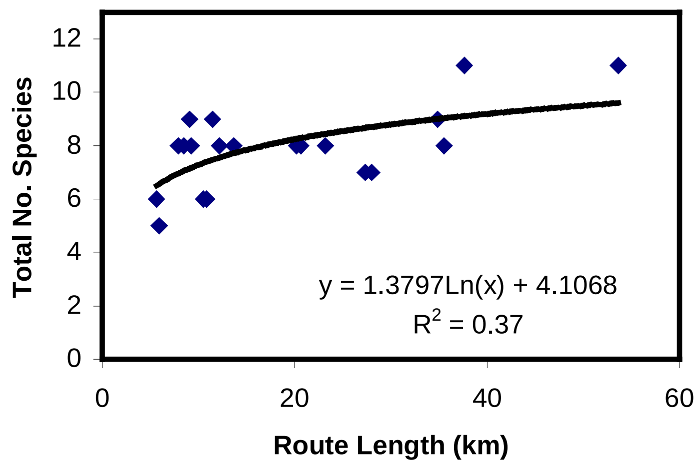
Species Detection

The 20 routes were surveyed 65 times, totaling 386 km. Tracks of 13 species were detected (Table 2.1). No sign was detected of long-tailed weasels, jaguar, or ocelot. It was not possible to distinguish between tracks of hooded and striped skunks, and they are hereafter referred to as *Mephitis* skunks. A total of 601 sign units was recorded, including tracks, scat, dens, carcasses, scrapes, and diggings. All but one species, black bears, were recorded at both Fort Huachuca and the NCA. The maximum number of species detected on any route was 11, with the average of 7.9 species per route. *Mephitis* skunks were detected on all 20 routes. Bobcats were detected on 19 routes; coyotes, gray fox, and hog-nosed skunks all followed with 18 routes, but they were not all the same routes (Table 2.1). Maps documenting sign of each species on each route appear later in this chapter.

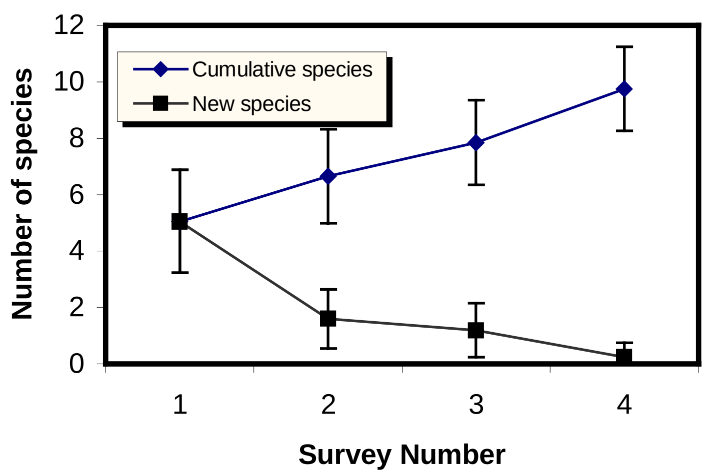
- Table 2.1. Species detected on routes surveyed from Oct. 1998-Jan. 2000, all kinds of sign included. X indicates that sign was recorded for the species at least once. Habitat type is majority habitat by km of route, from GIS vegetation layer.

Route	Predominant Habitat	Badger	Bear	Bobcat	Coati	Coyote	Gray fox	Hog-nosed skunk	Kit fox	*Mephitis* skunk	Puma	Raccoon	Ringtail	Spotted skunk	Total species
Ft. Huachuca:															
Antelope Pond	Grassland			X		X	X	X	X	X	X	X			8
Lower Garden	Grassland	X		X		X	X	X	X	X	X	X			9
Sewage Ponds	Grassland			X		X		X	X	X		X			6
Slaughterhouse	Grassland			X		X	X	X	X	X	X	X			8
E. Boundary	Scrub			X		X	X	X		X				X	6
Blacktail	Woodland		X	X	X	X	X	X		X				X	8
Bravo Break	Woodland		X	X	X	X	X	X		X	X				8
Sawmill Crest	Woodland		X	X	X		X	X		X	X		X		8
Split Rock	Woodland			X	X	X	X	X		X	X	X	X		9
Upper Huachuca	Woodland		X	X	X		X	X		X	X	X			8
San Pedro River:															
Hereford S	Grassland	X		X		X				X		X			5
Big Wash	Riparian	X		X		X	X	X	X	X	X	X			9
Boquillas	Riparian			X	X	X	X	X	X	X	X	X	X	X	11
Charleston	Riparian					X	X	X		X	X	X			6
Palominas	Riparian	X		X		X	X	X		X		X			7
San Pedro N	Riparian	X		X		X	X		X	X	X	X			8
Fairbank	Scrub			X	X	X	X	X		X	X	X			8
Hereford N	Scrub	X		X		X	X	X		X	X	X			8
Murray Springs	Scrub			X		X	X	X	X	X		X			7
San Pedro S	Scrub	X		X		X	X	X	X	X	X	X	X	X	11
Total Routes		7	4	19	7	18	18	18	9	20	14	16	4	4	

The number of species detected increased with total route length (route length x number of surveys; $F_{1,18}$ = 10.38, P = .0047; Fig. 2.2) and number of surveys (Fig. 2.3). The average number of new species added declined after each survey, to almost zero by the fourth survey (Fig. 2.3).



• Figure 2.2. The number of species detected on routes of various lengths. See methods for calculations.



• Figure 2.3. The total number of species, and number of new species detected with each subsequent survey conducted on Fort Huachuca and the San Pedro Riparian NCA, October 1998-January 2000. Symbols represent means of all routes, and vertical bars represent standard deviations.

Use of Habitats

Of 10 species with large enough sample sizes to test, the sign of four species was distributed among vegetation types in proportion to availability, the remaining six differed among vegetation types (Table 2.2). In general, sign of badgers was detected more in grassland; coyotes in grassland and scrub; gray fox and hog-nosed skunks in scrub and woodland; coatis in woodland and raccoons in riparian more than expected based on availability of these habitat types. Sign of bobcat, kit fox, puma, and *Mephitis* skunks was detected in proportion to availability of habitat.

• Table 2.2. Proportional detectability of sign of different species in various vegetation types, October 1998-January 2000. Numbers represent proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of proportions against availability. Shaded cells indicate values greater than expected based on availability. See methods for description of vegetation types and calculations. Too few sign units from black bear, ringtails, and spotted skunks were detected for analysis.

	Vegetation Type						
Species	**Grass**	**Scrub**	**Woodland**	**Riparian**	**N**	**G**	**P**
Badger	.40	.40	.13	.07	15	12.53	.0058
Bobcat	.17	.38	.14	.31	81	0.52	.9146
Coati	0	.11	.78	.11	18	43.25	.0000
Coyote	.30	.51	.11	.09	93	33.96	.0000
Gray fox	.15	.39	.32	.14	74	29.39	.0000
Hog-nosed skunk	.19	.47	.23	.12	43	12.71	.0053
Kit fox	.21	.50	.07	.21	14	1.692	.6386
Mephitis skunk	.17	.39	.17	.27	109	3.60	.3085
Puma	.16	.29	.21	.34	68	4.62	.2015
Raccoon	.20	.29	.04	.47	70	9.55	.0228
Average	.19	.38	.19	.24			
Availability	**.19**	**.36**	**.12**	**.33**			

Of the same 10 species, six used topographic classes in proportion to their availability; the remaining four showed significant differences among categories (Table 2.3). Coati sign was detected more often than expected on ridges and side hills, and less often on flats. Gray fox sign was detected less often in washes and more often on sidehills than expected. Puma and raccoon sign was detected more often in washes and less often on flats than expected.

• Table 2.3. Proportional detectability of sign of different species in various topographic situations, October 1998-January 2000. Numbers represent proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of proportions against availability. Shaded cells indicate values greater than expected based on availability. Too few sign units from black bear, ringtails, and spotted skunks were detected for analysis.

	Topography						
Species	**Ridge**	**Wash**	**Sidehill**	**Flat**	**N**	**G**	**P**
Badger	.07	.13	.13	.67	15	7.12	.0682
Bobcat	.05	.48	.06	.41	81	1.79	.6180
Coati	.22	.50	.22	.06	18	14.70	.0021
Coyote	.06	.31	.11	.50	93	5.65	.1297
Gray fox	.15	.34	.16	.32	74	10.41	.0154
Hog-nosed skunk	.04	.40	.12	.42	43	1.41	.7026
Kit fox	.07	.50	.14	.29	14	1.19	.7553
Mephitis skunk	.05	.50	.07	.38	109	3.08	.3789
Puma	.09	.59	.07	.24	68	9.19	.0269
Raccoon	.03	.57	.06	.31	70	8.63	.0346
Average	.08	.45	.10	.37			
Availability	**.08**	**.44**	**.08**	**.40**			

Of seven species with large enough sample sizes, most sign was detected < 50 m from washes (Table 2.4). Approximately half of the sign of each species was detected within 10 m of washes, and about a quarter > 50 m away from washes.

• Table 2.4. Proportional detectability of sign of different species at various distances from washes October 1998-March 1999. Numbers represent proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of equal proportions among classes. Shaded cells indicate values greater than expected based on availability. Too few sign units from badger, black bear, coati, kit fox, ringtails, and spotted skunks were detected for analysis.

Distance to wash							
Species	**< 10 m**	**11-20 m**	**21-50 m**	**> 50 m**	**N**	**G**	**P**
Bobcat	.54	.11	.03	.32	37	25.94	.0000
Coyote	.45	.12	.10	.35	52	19.13	.0001
Gray fox	.43	.06	.20	.31	35	12.18	.0068
Hog-nosed skunk	.50	.18	.09	.23	22	7.70	.0213
Mephitis skunk	.52	.06	.19	.23	52	23.50	.0000
Puma	.67	.06	.06	.22	36	33.16	.0000
Raccoon	.71	.03	.03	.24	38	46.43	.0000
Average	.54	.08	.11	.27			
Expected	**.25**	**.25**	**.25**	**.25**			

Of seven species with adequate sample sizes, all were located > 50 m from water more often than expected (Table 2.5). Sign was detected > 50 m from water least often in raccoons, and most often for coyotes and hog-nosed skunks.

• Table 2.5. Proportional detectability of sign of different species at various distances from surface water, October 1998-January 2000. Numbers represent proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of equal proportion among classes. Shaded cells indicate values greater than expected based on availability. Too few sign units from badger, black bear, coati, kit fox, ringtails, and spotted skunks were detected for analysis.

Distance to water							
Species	**< 10 m**	**11-20 m**	**21-50 m**	**> 50 m**	**N**	**G**	**P**
Bobcat	.19	.07	.09	.65	81	63.52	.0000
Coyote	.09	.02	.03	.85	93	154.07	.0000
Gray fox	.09	.05	.09	.76	74	84.59	.0000
Hog-nosed skunk	.07	.02	.05	.86	43	72.33	.0000
Mephitis skunk	.20	.08	.08	.62	109	76.68	.0000
Puma	.24	.09	.13	.54	68	31.66	.0000
Raccoon	.36	.09	.10	.46	70	30.79	.0000
Average	.17	.06	.07	.69			
Expected	**.25**	**.25**	**.25**	**.25**			

Of 7 species with enough data to test, all were detected at < 25% canopy cover more than expected (Table 2.6).

• Table 2.6. Proportional detectability of sign of different species at various levels of canopy cover, October 1998-March 1999. Numbers represent proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of equal proportions among classes. Shaded cells indicate values greater than expected based on availability. No sign was detected at canopy cover values >75%. Too few sign units from badger, black bear, coati, kit fox, ringtails, and spotted skunks were detected for analysis.

Percent Canopy Cover						
Species	**< 25%**	**26-50%**	**51-75%**	**N**	**G**	**P**
Bobcat	.68	.19	.14	37	18.37	.0001
Coyote	.67	.25	.08	52	29.98	.0000
Gray fox	.66	.23	.11	35	16.62	.0002
Hog-nosed skunk	.82	.14	.14	22	22.98	.0000
Mephitis skunk	.73	.15	.12	52	34.56	.0000
Puma	.57	.27	.16	37	9.52	.0086
Raccoon	.74	.18	.08	38	27.48	.0000
Average	.67	.21	.12			
Expected	**.33**	**.33**	**.34**			

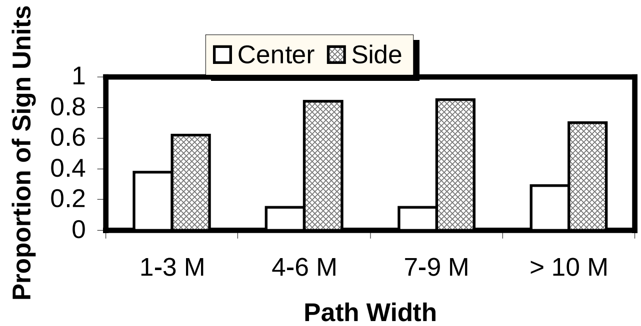
Of seven species with enough data to test, all chose paths of narrower width, with almost 50% of sign recorded on paths ≤ 3 m wide (Table 2.7).

• Table 2.7. Proportional detectability of sign of different species on paths of various widths, May 1999-January 2000. Numbers represents proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of equal proportions among classes. Shaded cells indicate values greater than expected based on availability. Too few sign units were detected from badger, black bear, coati, kit fox, ringtails, and spotted skunks for analysis.

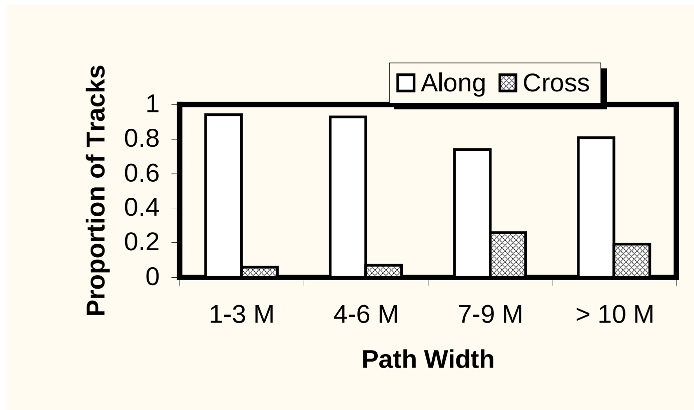
Path Width							
Species	**1-3 m**	**4-6 m**	**7-9 m**	**> 10 m**	**N**	**G**	**P**
Bobcat	.54	.25	.05	.16	44	24.30	.0000
Coyote	.54	.20	.12	.15	41	16.04	.0003
Gray fox	.42	.29	.21	.08	38	10.24	.0059
Hog-nosed skunk	.40	.35	.20	.05	20	7.23	.0270
Mephitis skunk	.46	.23	.16	.16	57	12.34	.0021
Puma	.47	.23	.17	.13	30	7.43	.0244
Raccoon	.51	.26	0	.23	31	22.28	.0001
Average	.48	.26	.12	.13			
Expected	**.25**	**.25**	**.25**	**.25**			

There was a tendency to leave sign on the side, rather than in the center, of wider paths (Fig. 2.4). Tracks detected along wider paths were more likely to be crossing the path than on narrower paths (Fig. 2.5).

• Figure 2.4. The proportion of sign left on the center or side of paths of various widths. All sign types and all species combined. N = 255.



• Figure 2.5. The proportion of tracks crossing or following along paths of various widths. Tracks of all species combined. N = 258.



For most species, sign was not detected on different surfaces in proportion to their availability. Sign of coyotes, coatis, gray fox, and kit fox appeared on surfaces in proportion to their abundance, sign of most other species was detected more on washes and trails than their proportional abundance (Table 2.8).

• Table 2.8. Proportional detectability of sign of different species on different surfaces, October 1998-January 2000. Numbers represents proportion of total sign units; N = the total number of sign units; G = log-likelihood statistic for test of proportions against availability. Shaded cells indicate values greater than expected based on availability. Roads were currently or formerly used by vehicles, and at least 2 m wide. Trails were not used by vehicles, and generally < 2m wide. Too few sign units were detected from black bear, ringtails, and spotted skunks for analysis.

	Surface					
Species	**Road**	**Wash**	**Trail**	**N**	**G**	**P**
Badger	.40	.13	.47	15	17.69	.0001
Bobcat	.44	.38	.17	81	19.73	.0000
Coati	.78	.17	.06	18	1.05	.5927
Coyote	.57	.27	.16	93	4.062	.1312
Gray fox	.58	.27	.15	74	5.87	.0531
Hog-nosed skunk	.56	.26	.19	43	6.52	.0385
Kit fox	.36	.50	.14	14	5.72	.0574
Mephitis skunk	.47	.36	.17	109	22.95	.0000
Puma	.31	.50	.19	68	38.06	.0000
Raccoon	.31	.53	.16	70	36.99	.0000
Average	.47	.36	.17			
Availability	**.67**	**.26**	**.07**			

The overall difference persisted even when roads regularly used by vehicles (Blacktail, Boquillas, Palominas, and Sewage Ponds) were removed from the sample (N = 485, G = 85.34, P = .0000). On less traveled roads, only sign of hog-nosed skunk changed to being detected on surfaces in proportion to their availability.

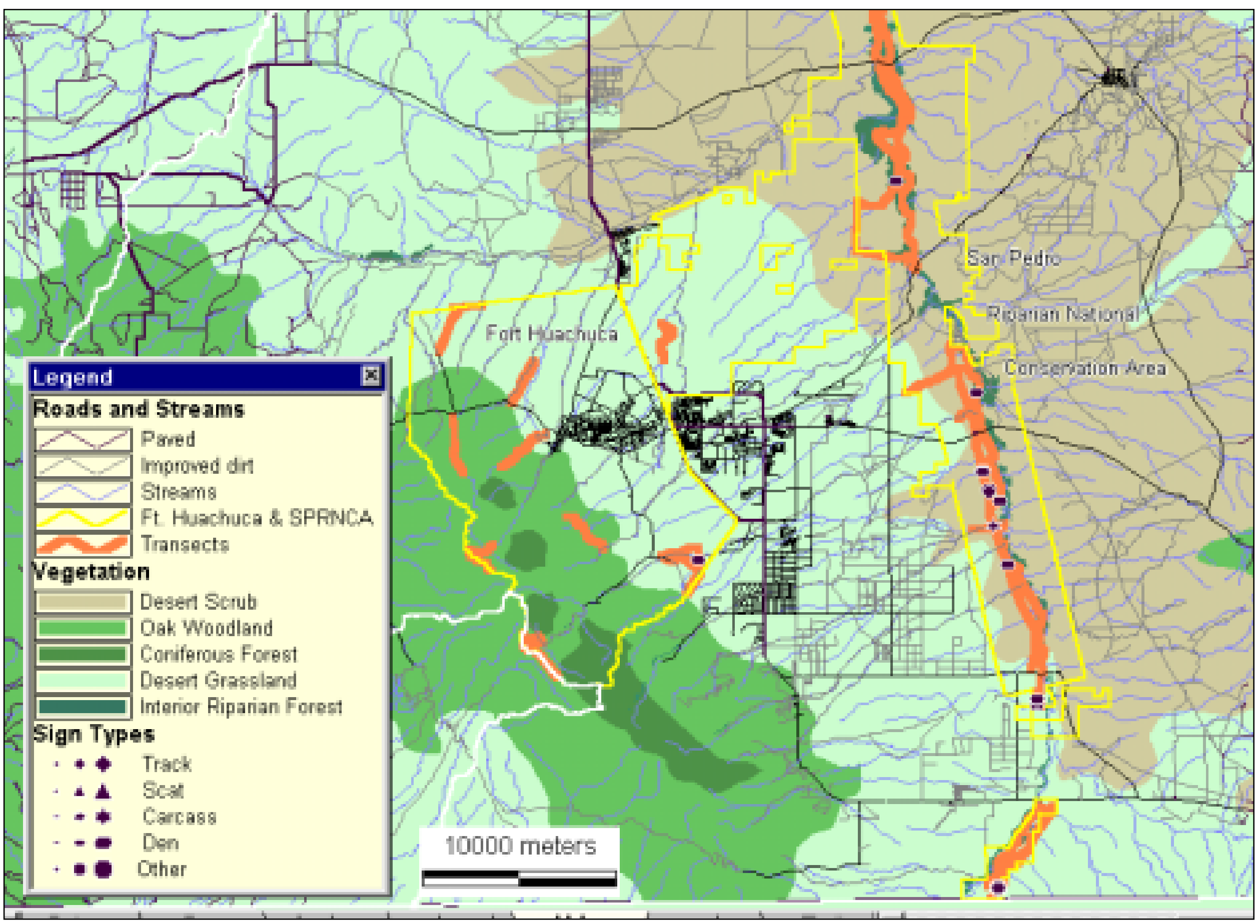
Carnivore Diversity

Carnivore diversity was highest on woodland routes (mean=0.88 species/km), lowest on scrub/grassland routes (mean=0.46 species/km), and in between on riparian routes (mean = 0.52 species/km; $F_{2,17} = 4.89$, P = 0.0210). Carnivore diversity did not differ with either index of urbanization (urban code: $F_{2,17} = 1.51$, P = 0.2483; distance to dwellings: $F_{1,18} = 0.12$, P = 0.7340). Carnivore diversity also did not differ with distance from the international border ($F_{1,19} = 0.07$, p = .8023).

Species Summaries

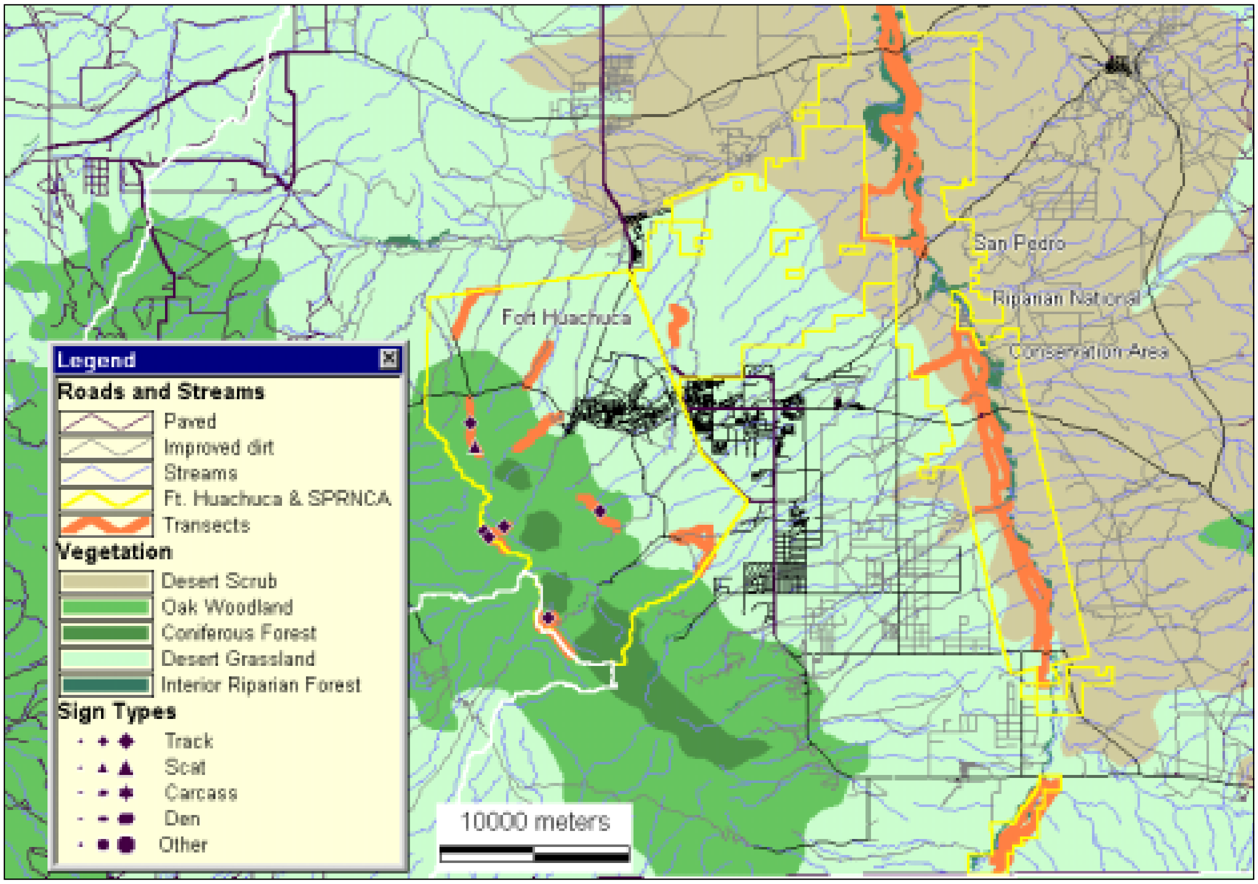
Badger – Badger sign was relatively uncommon and included 2 track sets, 11 areas of dens, 1 set of diggings, and 1 carcass. Sign was detected primarily in grassland/scrub habitats, in areas of low relief. Sign of badger usually consisted of dens, or setts, often located in cut banks or berms along the former agricultural fields along the San Pedro.

• Figure 2.6. Locations of badger sign detected from Oct 1998-Jan 2000.



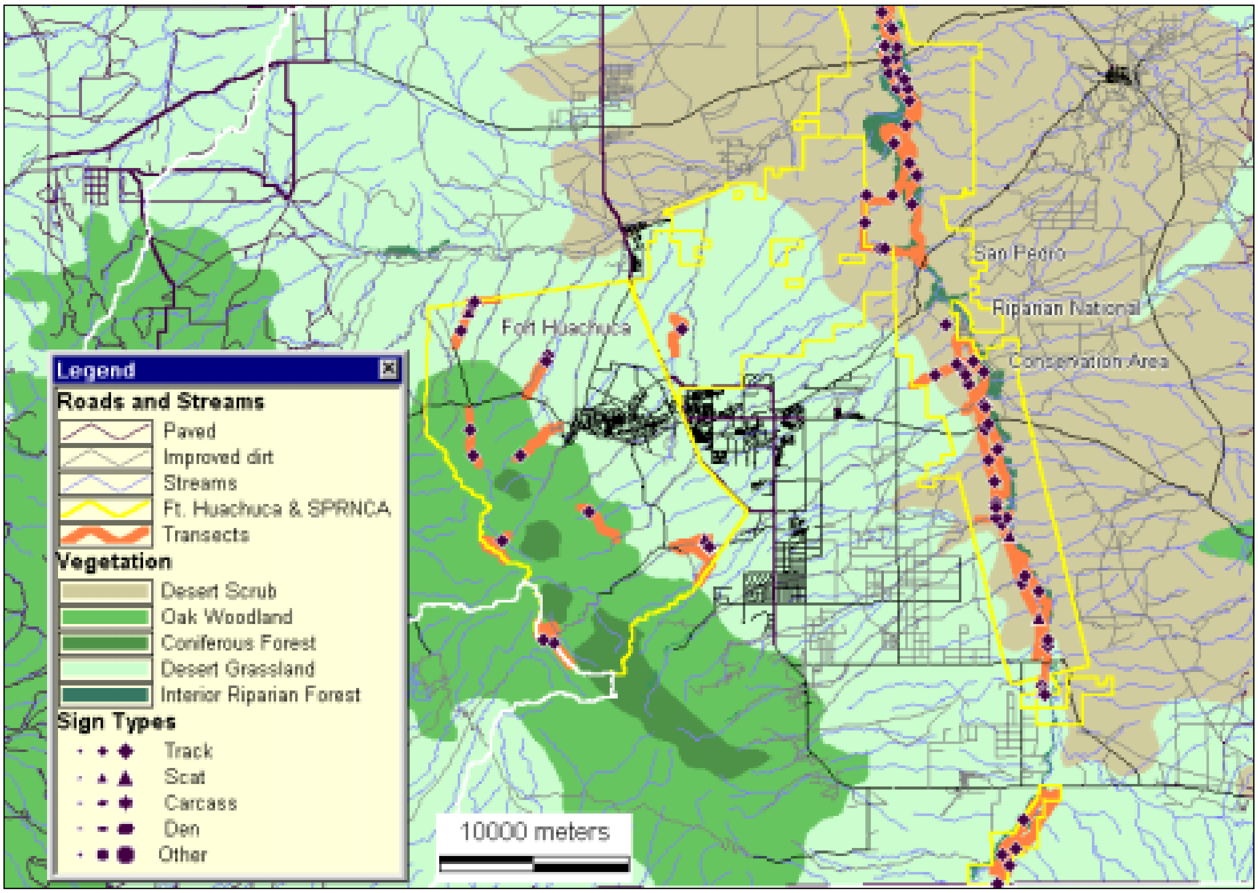
Black bear – Sign of black bear was very uncommon, with only 6 track sets and 1 scat recorded. Based on measurements, these track sets were made by at least 4 different bears. All sign was found on Fort Huachuca, in woodland habitat.

• Figure 2.7. Locations of black bear sign detected from Oct 1998-Jan 2000.



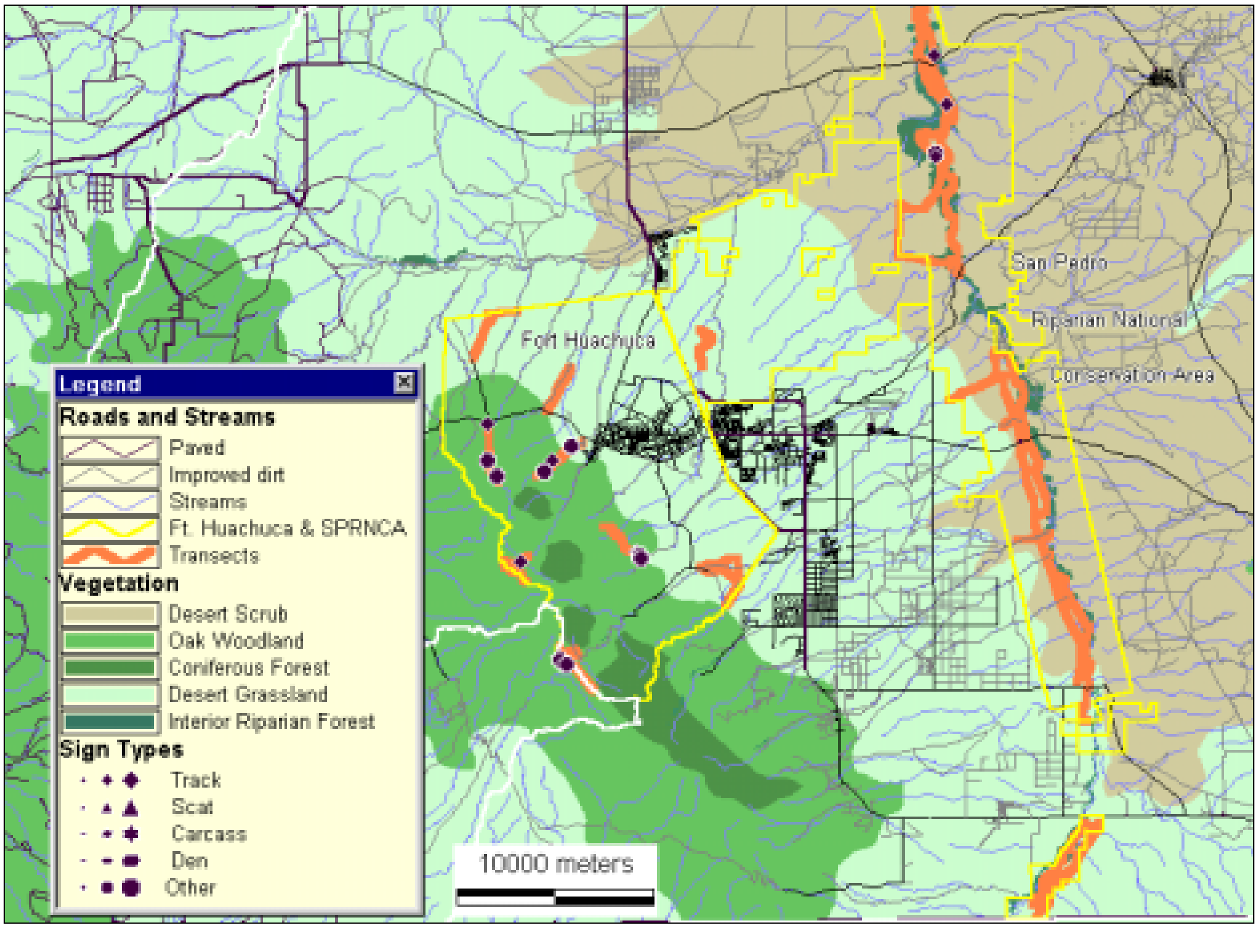
Bobcat – Sign of bobcat was very common, consisting of 75 track sets and 6 scats. Sign was detected on all but 1 route. Bobcat sign was found in vegetation types and topographic classes in proportion to their availability. Sign appeared more often in washes and on trails than on roads. Overall, bobcats appeared to be common habitat generalists, at least at the scale of this study.

- Figure 2.8. Locations of bobcat sign detected from Oct. 1998-Jan 2000.



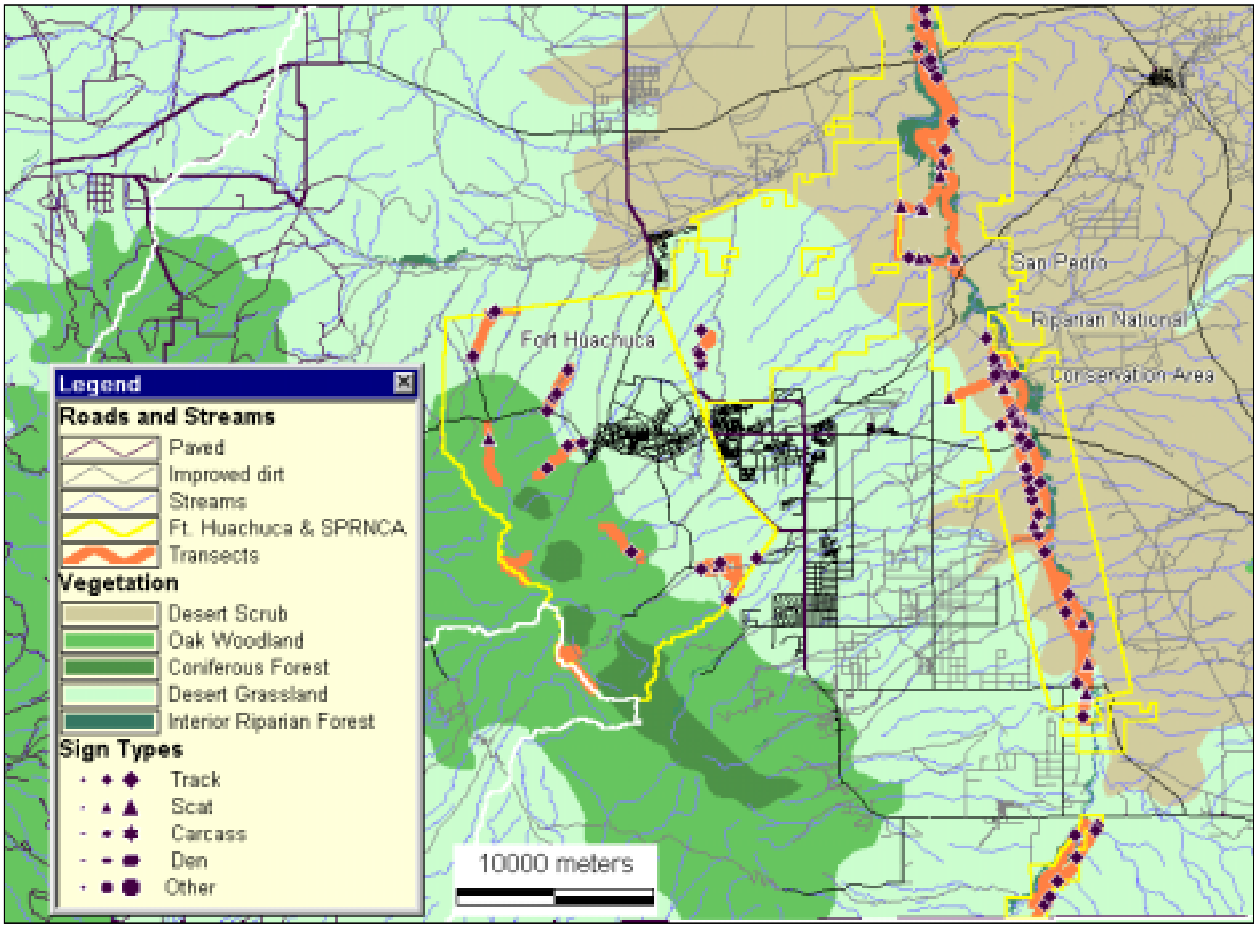
Coati – Coati sign was relatively rare, with 15 sets of tracks and nose circles, 1 set of diggings, and 2 observations of single animals. Coatis were primarily detected in woodland in the Huachucas, but 3 track sets and 1 observation came from the NCA. All sign and observations in the NCA were of solos; as was most of the sign in the Huachucas. Coati sign was detected most often on ridges and side hills, and most frequently on roads. During a 4-year study of coatis in the Huachucas, coati groups were seldom seen following roads, and generally crossed them quickly (pers. obs.). Adult males, on the other hand, often followed roads for ≥ 0.5 km, and thus were more likely to be detected in this type of study.

• Figure 2.9. Locations of coati sign detected from Oct 1998-Jan 2000.



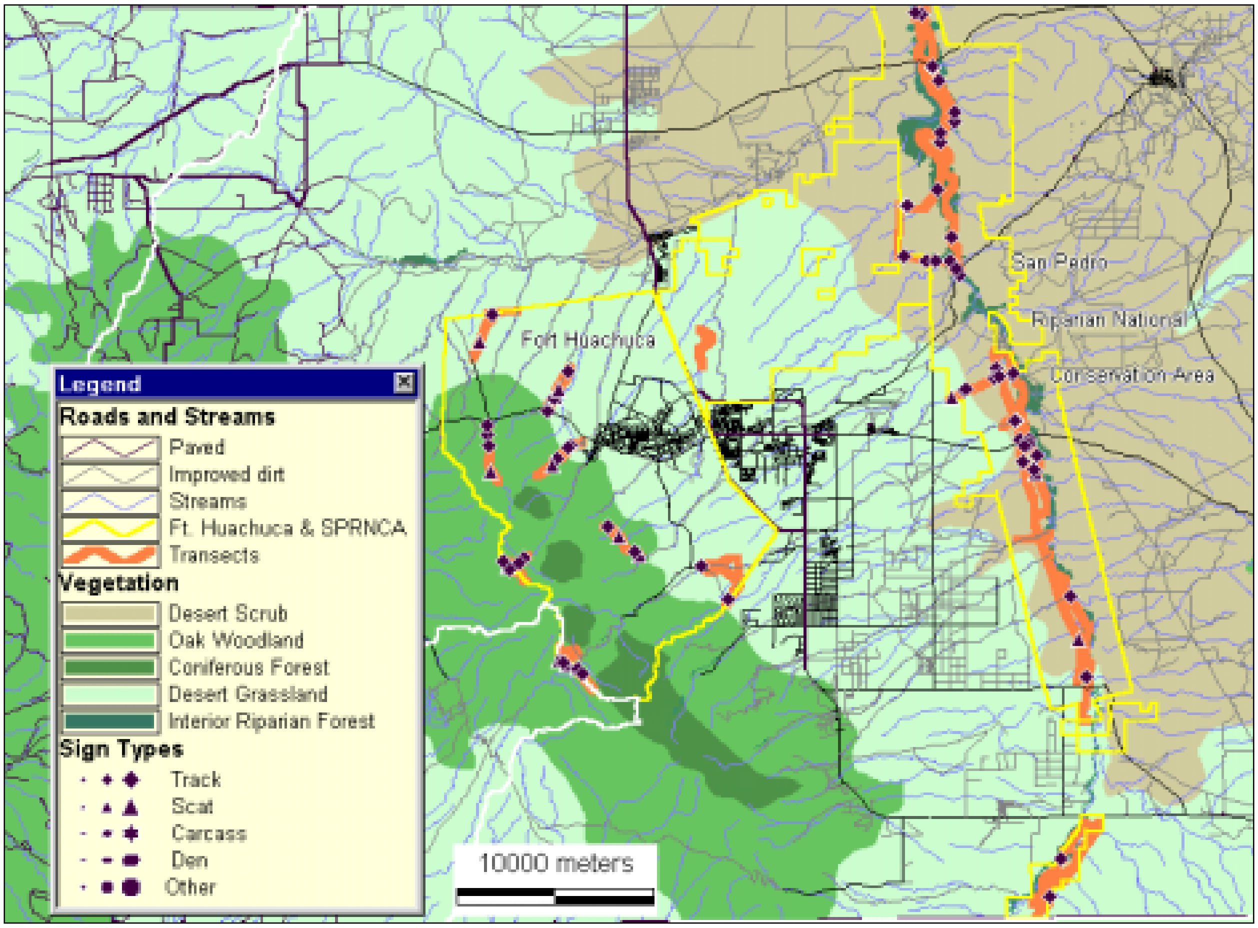
Coyote – Coyote sign was common, with 73 track sets and 20 scats detected during the study. Sign was detected on all routes, except for two routes along the crest of the Huachucas. Coyote sign was most frequently detected in grassland and scrub, with light canopy cover, and they appeared to use topographic classes in proportion to their availability. Sign was found in washes, roads, and trails in proportion to their availability, and sign was frequently detected > 50 m from water.

- Figure 2.10. Locations of coyote sign detected from Oct 1998-Jan 2000.



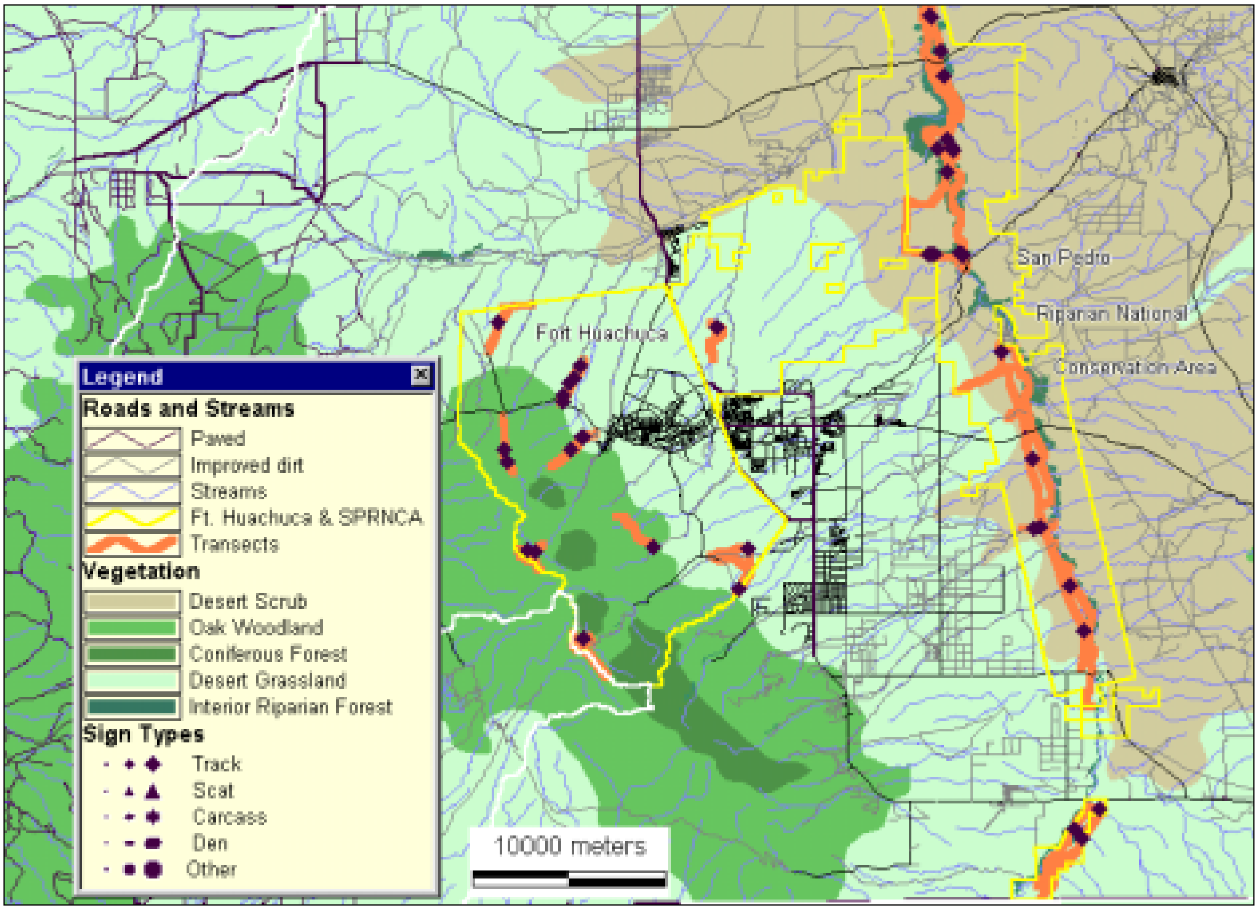
Gray fox – Sign of gray fox was common, with 60 track sets and 14 scats detected. Sign was found on nearly all routes, in predominantly scrub and woodland habitats. Gray fox sign was found most often on ridges and side hills, and less often in washes and flats. Sign was found in washes, roads, and trails in proportion to their availability, and sign was frequently detected > 50 m from water.

• Figure 2.11. Locations of gray fox sign detected during surveys from Oct 1998-Jan 2000.



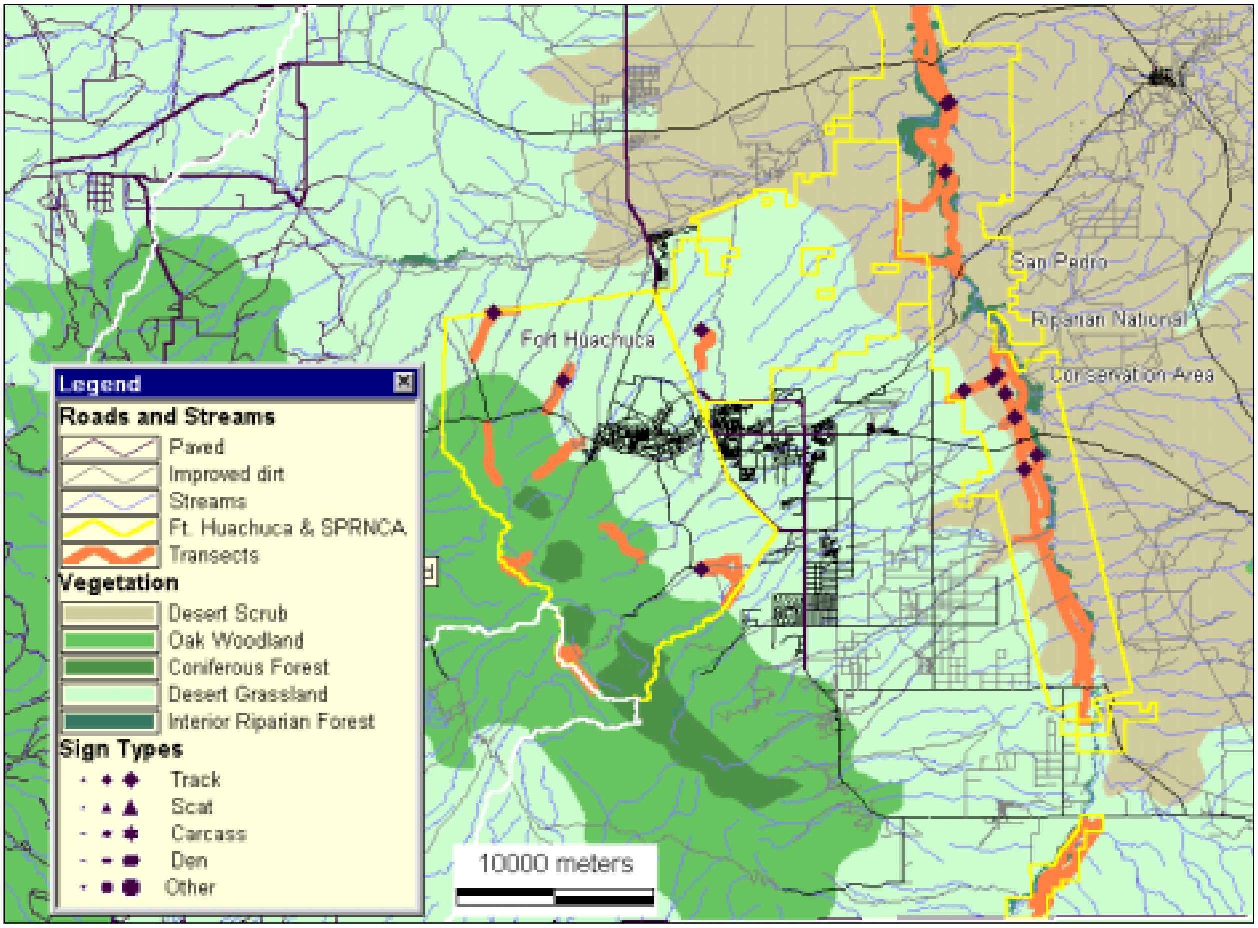
Hog-nosed skunk – Hog-nosed skunk sign was common, with 43 track sets detected. Tracks were detected most commonly in scrub and woodland habitats, and were detected among topographic classes in proportion to their availability. Tracks were most often detected < 10 m from washes, and in areas with sparse canopy cover. Sign was detected more often on trails than expected when all routes were analyzed, but when roads that receive regular vehicle traffic were removed, sign was detected in proportion to availability. This may indicate that hog-nosed skunks avoid roads with regular traffic, or that sign is less detectable there.

• Figure 2.12 Locations of hog-nosed skunk sign detected from Oct 1998-Jan 2000.



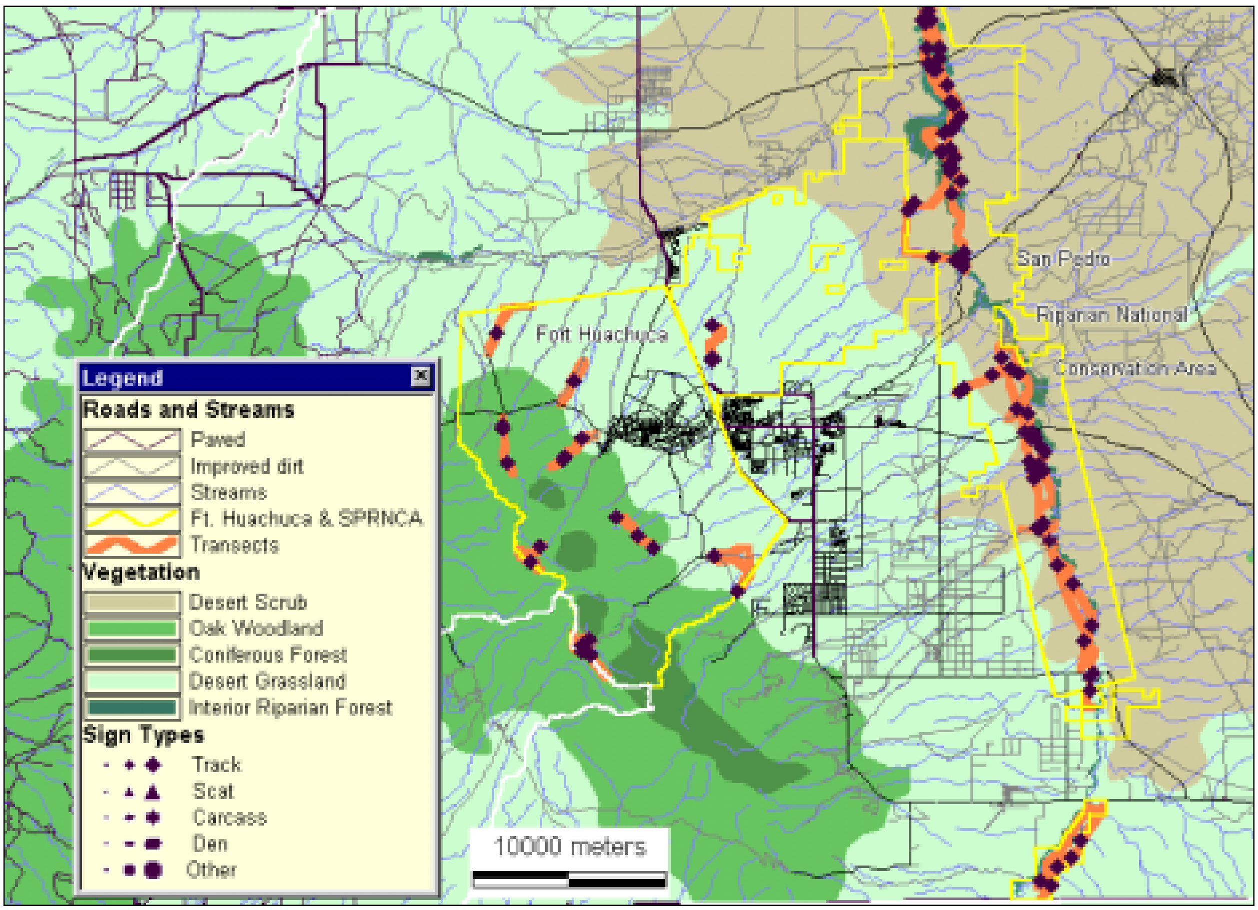
Kit fox – Kit fox sign was rare, with only 14 track sets detected. Tracks were found on 9 different routes; 4 on Fort Huachuca, and 5 in the NCA. Based on this small sample size, kit fox sign did not show significant differences among classes of vegetation or topography, but power for these tests was low.

• Figure 2.13. Locations of kit fox sign detected from Oct 1998-Jan 2000.



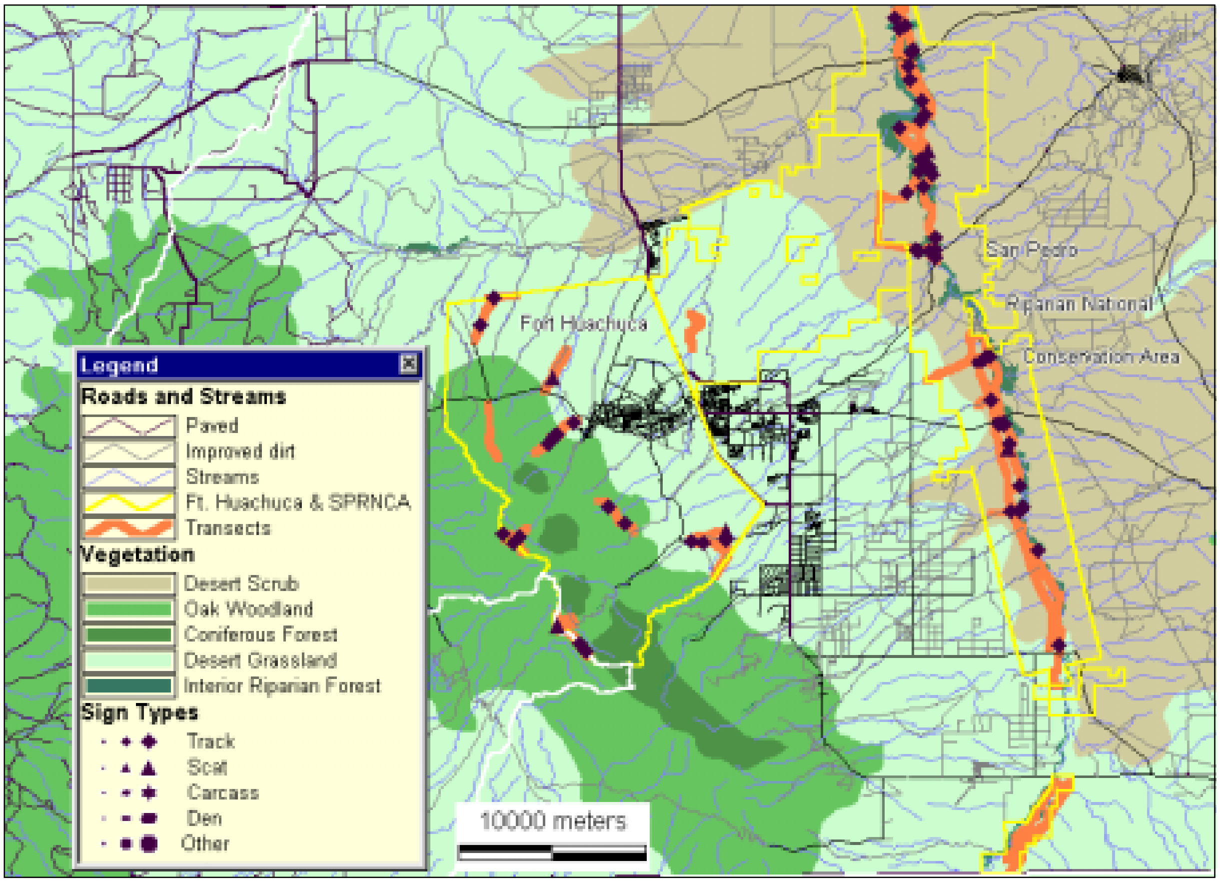
Mephitis skunks – skunks of the genus *Mephitis* were commonly detected, with 107 track sets detected, plus carcasses of 1 striped and 1 hooded skunk. Both carcasses were found in the NCA; one was a road kill, and the other was too decomposed and scavenged to determine cause of death. As a collective genus, sign was found among vegetation and topographic classes in proportion to their availability. Sign was frequently found < 10 m from washes, and in areas of sparse canopy cover. Sign was detected on paths of all width classes, but overall, sign was found more often in washes and trails than expected based on availability. Little is known about the resource partitioning between these two species.

- Figure 2.14. Locations of *Mephitis* skunk sign detected from Oct 1998-Jan 2000.



Puma – Puma sign was common, with 62 track sets, 5 scats, and 1 scrape recorded. Puma sign was detected on 14 routes, and was noticeably scarce on the southernmost routes in the NCA (Table 2.1). Sign was found in vegetation types in proportion to their availability, and more often < 10 m from washes and < 25% canopy cover. Sign was detected more frequently on washes and trails than roads. Based on track measurements, at least 4 different individuals were detected (Table 2.9). One individual, whose track was only found once, had a deformed toe, and was individually identifiable (Fig. 2.6).

- Figure 2.15. Locations of puma sign detected from Oct 1998-Jan 2000.



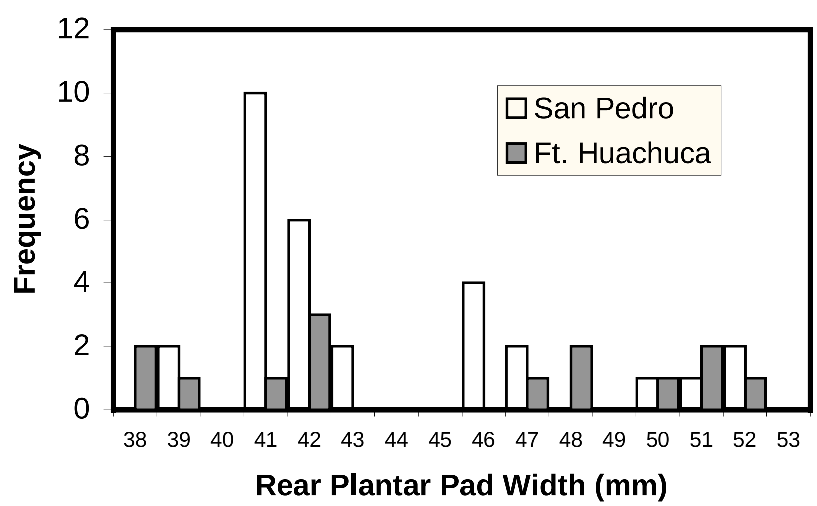
- Figure 2.16. Photograph of a track from a puma with a deformed toe. Track is from the left rear foot.

• Table 2.9. Rear foot plantar pad widths (mm) for puma tracks detected on Fort Huachuca and the San Pedro River during October 1998-January 2000. The first 5 routes are on Fort Huachuca, the remainder on along the San Pedro River. Measurements ± 1 mm may belong to the same individual, with the exception of *, which had a deformed foot and was thus uniquely identifiable.

	Survey			
Route	**1**	**2**	**3**	**4**
Antelope Pond		52	41	
Lower Garden			48	48, 52
Sawmill Crest	38	51		
Split Rock	50		47	
Upper Huachuca		42	42	
Big Wash	41	41, 46	41, 46	
Boquillas	43	42		41, 52
Charleston	43	42	41, 39	
Fairbank	41	41*, 47	42	
Hereford N			41, 46	
San Pedro N		41, 51	42	47
San Pedro S	42, 50	41, 42, 52	46	41

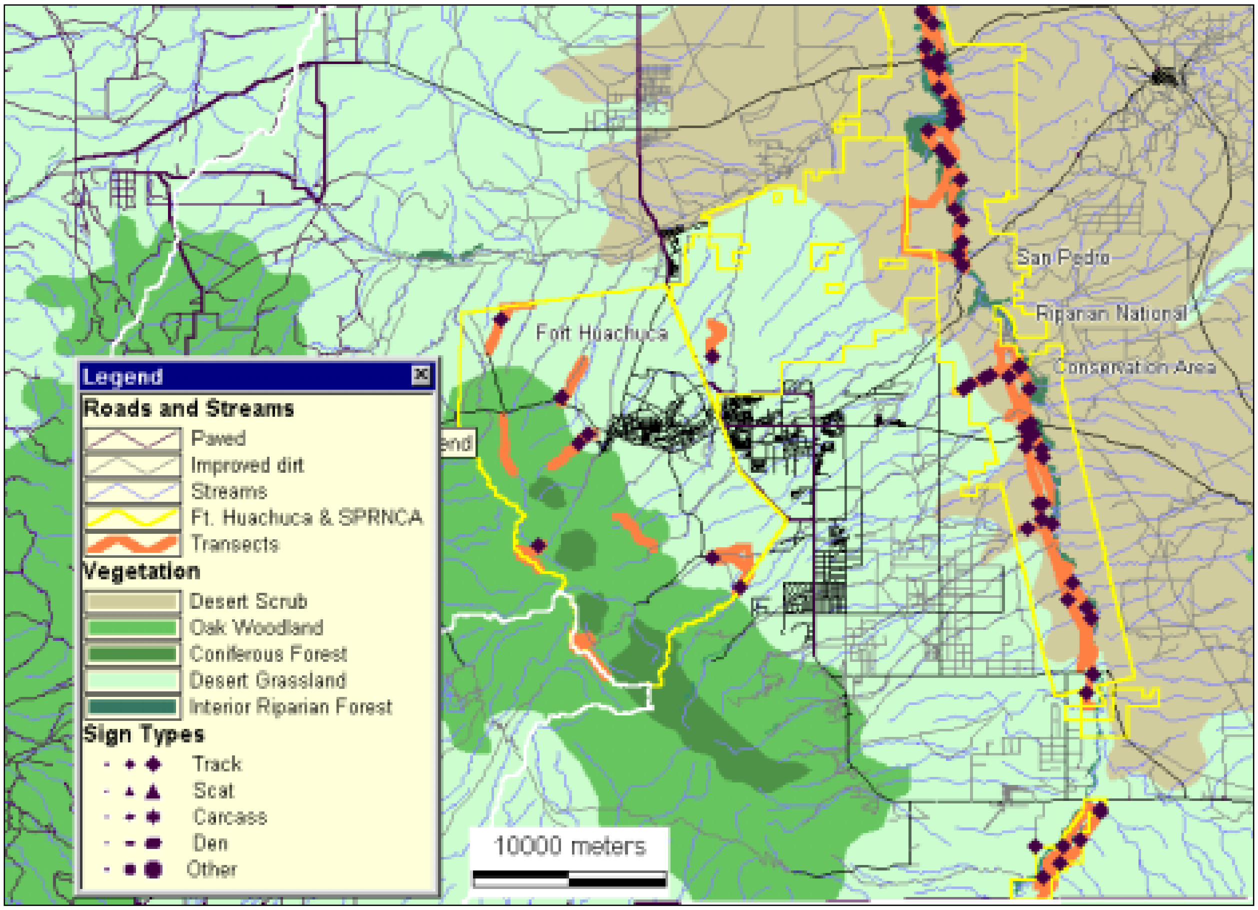
Frequency analysis of plantar pad widths revealed four clusters of measurements (Fig. 2.17). With the exception of the puma with the deformed toe, which was only detected in the NCA, it could not be determined if individuals in the Huachucas were the same as those in the NCA. Overall, pumas appeared to be common habitat generalists, at least at the scale of this study.

• Figure 2.17. Frequency analysis of puma plantar pad measurements from Table 2.9. Measurements ± 1mm may belong to the same individual.



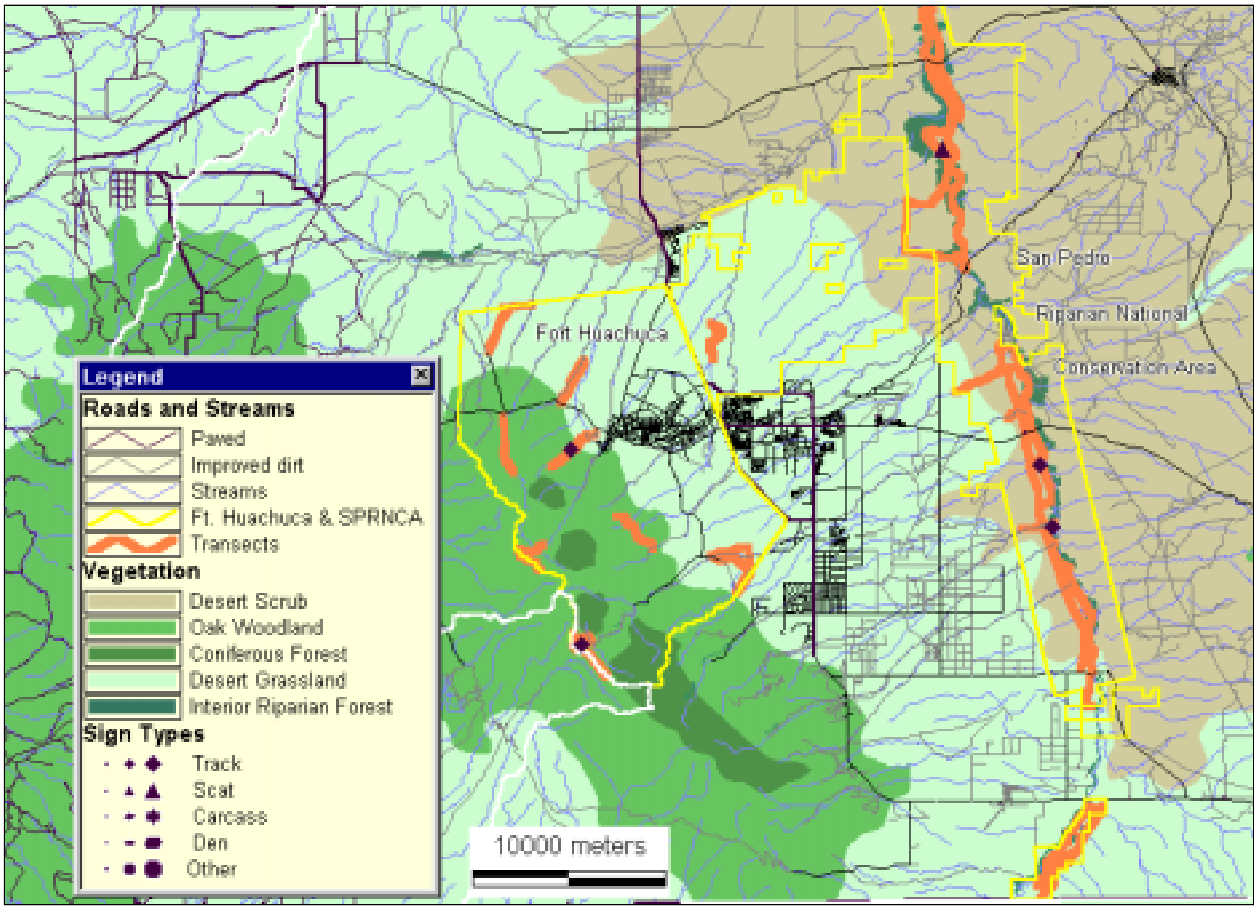
Raccoon – Raccoon sign was relatively common, with 69 track sets and 1 carcass detected. Not surprisingly, most raccoon sign was detected in riparian habitat and in washes, with 89% of sign found in the NCA. Almost half of the raccoon sign was > 50 m from water, with 92% of sign detected with < 50% canopy cover. As with many of the other carnivores, sign was detected with higher frequency on washes and trails than roads. Of the species detected in this study, raccoons appear most limited by habitat type.

• Figure 2.18. Locations of raccoon sign detected from Oct 1998-Jan 2000.



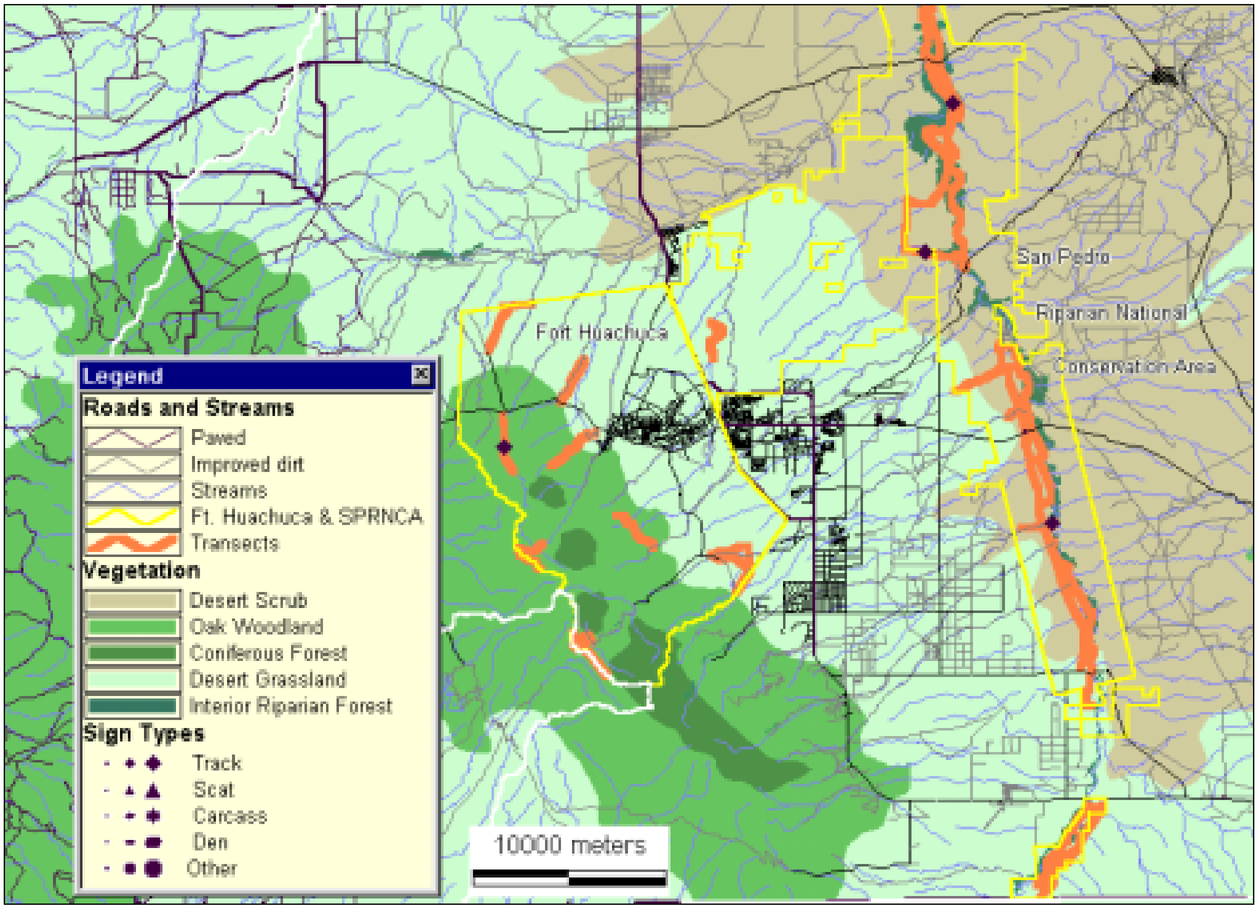
Ringtail – Ringtail sign was rare, with only 4 track sets and 1 scat found. Sign was found on both Fort Huachuca and the NCA. The number of sign units detected was too few to analyze. Due to their small size and possible desire for more cover or rockier habitats, I believe the lack of sign to be due to low detectability, and not due to rarity of the species.

• Figure 2.18. Locations of ringtail sign detected from Oct 1998-Jan 2000.



Spotted skunk – Sign of spotted skunks was rarest of all, with only 4 track sets discovered. Sign was found on both Fort Huachuca and the San Pedro River. As with ringtails, I believe the lack of sign to be due to poor detectability, rather than rarity of the species.

- Figure 2.19. Locations of spotted skunk sign detected from Oct 1998-Jan 2000.



Discussion

The track surveys detected all of the carnivore species known to currently inhabit Fort Huachuca and the San Pedro River area. The number of species detected increased with the number of surveys, indicating that >4 surveys may have been necessary to document all of the species using each route. Distribution patterns of sign, relative to vegetation type and topography, mirror patterns from specimen collections and observations presented in Hoffmeister (1986). Three species sought, but not detected, included jaguar, ocelot, and long-tailed weasel. Jaguars have been sighted recently in nearby mountain ranges, but no confirmed sightings have come from the Huachuca Mountains (Rabinowitz, 1999). Few records of ocelot are available; the most recent listing in Hoffmeister (1986) is of an ocelot taken by a hunter near Patagonia in 1960. Although Hoffmeister (1986) and Hoffmeister and Goodpastor (1954) document a few specimens of long-tailed weasels in the area, no sign was detected during this study, nor during 4 years of carnivore studies on Fort Huachuca (pers. obs.). They appear to be very rare in the area, and efforts should be made to learn more about their distribution and abundance in southeastern Arizona.

During 1987, a furbearer study consisting of live-trapping, scent-stations, and foot surveys along the San Pedro River had similar results to those here, relative to abundance of carnivore species. Ringtails, spotted skunks, and coatis were considered rare along the San Pedro River, whereas badgers, coyotes, gray fox, raccoons, striped and hog-nosed skunks and bobcats were quite common (Duncan, 1988; Woolsey, 1987). Woolsey (1987) reported more sign of kit fox and black bear, and less of puma than detected during this study. No sign of long-tailed weasel, jaguar, or ocelot were found (Woolsey, 1987).

No sign of black bear was detected along the San Pedro River during this study, although recent sign has been detected near the Babocomari confluence (H. Shaw, pers. comm.), and near Palominas (unnamed Palominas resident, pers. comm.). Sign of puma was very common in both the Huachucas and along the San Pedro River. It could not be determined if there was movement between the two areas by puma; most puma sign was relatively close to the river, and no sign was found > 1 mile from the river. Based on repeated observations of similar-sized tracks, it appear as if an adult male and an adult female regularly used the San Pedro as part of their home ranges, and at least one subadult moved through the area. Sign of raccoon, javelina and deer were plentiful along the river, in addition to cattle that occasionally wandered through cut fences, indicating that abundant food was available to the pumas. In early April 2000, Border Patrol officers on horseback observed a puma with "brand new" kittens on the San Pedro River near Fairbank (unnamed Border Patrol agent, pers. comm.), possibly indicating active reproduction within the NCA. During a study of three radio-collared pumas in the Huachuca Mountains, none moved from the mountains to the San Pedro River during 2 years of monitoring (Germaine and Bristow, 1997; Germaine, in litt.).

Given the proximity to the mountains and the lack of paved roads, the absence of several species on the Palominas route was surprising. No sign of black bear, coati, or puma were detected; however, biologists observed three young coatis near Palominas during June 2000 (D. Crawford, pers. comm.). Residents of the area report observations of all three species in past years. The influence of large amount of illegal immigrant traffic was noticeable, accompanied by large amounts of trash and human waste. The BLM estimates that as many as 500 immigrants a day are moving north along the San Pedro River (Ibarra, 2000). As much of this traffic occurs at night (pers. obs.), the potential exists for significant impact on nocturnal carnivores. In contrast, the hundreds of people visiting the San Pedro House area during peak birding season apparently had little impact on carnivores – that route had among the highest number of species recorded. This visitation is limited to daytime use only. Other studies have found that amount and timing of human activity influence distribution and behavior of wildlife (Griffiths and van Schaik, 1993; Clevenger and Waltho, 2000).

With a few exceptions, the tracking study appeared to be a very cost effective way to monitor distribution and habitat use of carnivores in this area. Exceptions included ringtails and spotted skunks, and possibly coatis. Although the study was able to determine the presence of these species, no information on distribution or abundance could be obtained. Other methods, such as live-trapping or photographic bait stations may be more useful to monitor these species. If the patterns in sign detection reflect patterns of habitat use, then the study identified species-specific patterns of habitat use. In terms of travel surfaces, all species used roads, trails, and washes, however, trails and washes were preferred to roads.

It was not possible with the tracking study to identify movement corridors between the Huachuca Mountains and the San Pedro River. The carnivore populations in both areas were abundant and diverse. From the data presented here, it appears as if the NCA provides considerable year-round habitat for most of the carnivore species, and may act as a corridor or an oasis for black bears and coatis. As discussed in the next chapter, few access opportunities exist for large carnivores to move between the Huachucas and the San Pedro River. It is possible that carnivores move to the San Pedro River from other areas, or that some may be relict populations.

Chapter 3: Wildlife movement potential between the Huachuca Mountains and San Pedro River

Methods

The tracking study revealed that most species use washes for travel, and that some species, such as coatis and black bears, are found predominantly in woodland. Because corridors should be species-specific (Harrison, 1992; Soulé, 1991), I focused on three species: puma because of their large area requirements; black bears because of their large area requirements and their woodland affinities; and coatis because of their woodland affinities and limited dispersal abilities (Gompper et al., 1992; Hass, 1997). I focused on washes as potential travel corridors, and limited my analysis to those washes that originated within woodland habitat in the Huachucas, and terminated at or within 1 km of the San Pedro River.

Identifying suitable washes

A numerical model was developed to rank individual washes for their suitability as potential wildlife corridors. Three assumptions went into the model:

- Linear habitats with cover provide the best movement potential between sites (Soulé, 1991);
- Roads and housing areas pose significant barriers to movement, through avoidance behavior by some species, road-related mortality, and negative interaction with humans (Bennett, 1991; Forman, 2000; Noss, 1995; Trombulak and Frissell, 2000);
- Shorter paths are better, to reduce travel- and dispersal-related mortality (Lindenmayer and Nix, 1993; Newmark, 1993; Soulé, 1991).

GIS layers used for analysis

The primary layers used for analysis included 1:100K DLG data for roads and streams from USGS (1994 or earlier), and vegetation (1980) and land ownership (1997) from Arizona State Lands Department (ALRIS). Derived layers included a road reclassification according to road width and traffic levels, and a layer of 100 m buffers placed along washes that fit the criteria of connectivity between the Huachucas and the San Pedro River. Buffers of 100 m were chosen to include the entire wash with some surrounding cover (Harris Environmental Group, 1997). A 300 m x 300 m grid was created, and cells within the grid were assigned values of housing density based on a map generated by the Defense Mapping Agency in 1994, on digital orthophotos taken in 1995 (from TerraServer®), and by placing a dot at each county 911 address in the non-incorporated area (layer from Scott Bassett of the Harvard Graduate School of Design).

A road score was calculated as the weighted total of the number of roads in each category intersecting the 100 m buffer along each wash. Road classification included: dirt connecting roads; 2-lane paved roads with little nighttime traffic; 4-lane or 2-lane paved roads with high day or nighttime traffic and stream crossings consisting of bridges; and 4-lane or 2-laned paved roads with high traffic and stream crossings consisting of box culverts. Hiking and jeep trails were also classified, but they were believed to have little impact on wildlife movements, and so were excluded from analysis. Weights appear in Table 3.1.

An urban score was calculated as the weighted total of the number of cells in each category within the buffer zone. Categories included:

Low: 1 house/4+ acres
Moderate: 1 house/2-4 acres
High: 1-4 houses/acre
Very high: > 5 houses/acre.

Weights appear in Table 3.1. An impedance score was calculated for each wash as follows:

$$I_k = \sum r_i w_i + \sum u_j w_j + d_k$$

Where I_k is the impedance score for the k^{th} wash; r_i is the count of cells in each roads category i; w_i is the category-specific weight; u_j is the count of cells in each urban category j; and d_k is the distance in km from 1 km inside the woodland interface to the San Pedro River along the midline of the wash. Although road scores and urban scores were not completely independent (urban areas tended to have many roads), both scores were entered into the model because of the additional effects of road-related mortality. The program Manifold® (CDA International, 1999) was used for GIS analysis, and the model was developed in Microsoft® Excel.

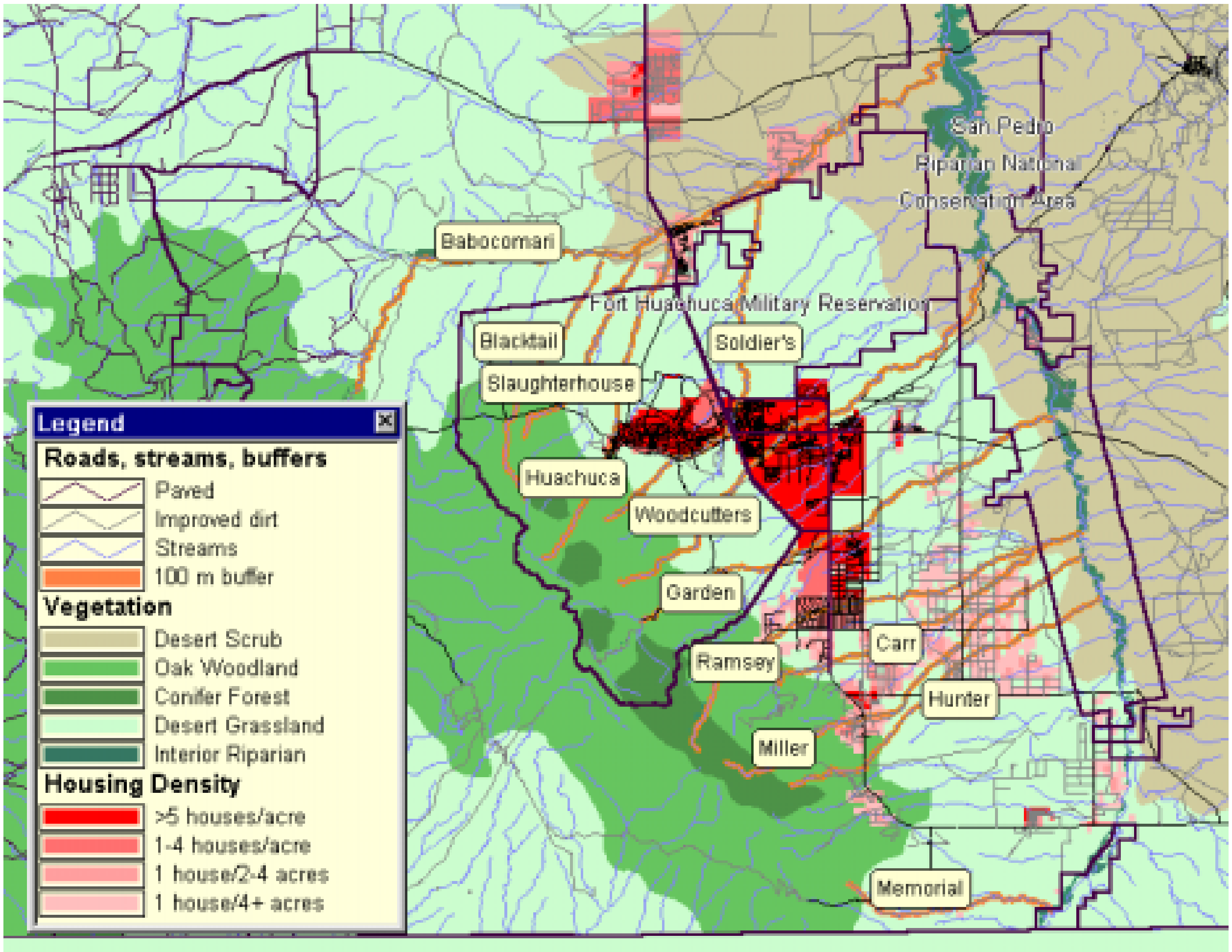
Results

Twelve washes fit the criteria of connectivity from the Huachuca Mountains to the San Pedro River (Fig. 3.1). Washes draining Ash and Stump Canyons were not included because they terminate > 1 km from the river. Washes, listed in order of their potential suitability (inverse of impedance) are presented in Table 3.1. The most suitable potential corridor, according to this model, was a wash draining the east slope of Coronado National Memorial (wash unnamed, referred to here as Memorial Wash). The only impediments on this wash were a dirt road and the 2-lane highway leading from Sierra Vista to the Memorial. The wash drains the mountains at about their closest point to the San Pedro River, and thus provides the shortest distance to travel between the sites. The next most suitable washes were Hunter, Carr, Miller, and Ramsey Canyons, all located south of Sierra Vista. Animals traveling along these washes have to cross State Route 92, which is a 4-lane highway over Ramsey, Carr, and Miller washes, and a 2-lane highway over Hunter wash. All crossings are box culverts. In addition, all four washes run through extensive areas of low to moderate density housing northwest of Hereford or south of Sierra Vista. The next most suitable washes are those draining Fort Huachuca to the north, where they meet the Babocomari River, which then joins the San Pedro River near Fairbank. The long distance an animal would have to travel along these washes to get to the San Pedro River (>30 km) was viewed as an impediment. Other impediments on these washes included numerous dirt roads and low and moderate density housing along the Babocomari.

The least suitable washes for potential wildlife corridors included Huachuca Canyon, Soldier's Wash and Woodcutter's Wash. All three move through high density housing on Post or in Sierra Vista. Huachuca and Soldier's Washes drain into the Babocomari, and have some of the same impediments as Babocomari and Slaughterhouse washes. Woodcutter's Wash flows under Buffalo Soldier's Trail, and then through some of the most densely urbanized areas of Sierra Vista. It lies adjacent to a 4-lane bypass currently being constructed near Veterans Memorial Park and Apache Middle School, and adjacent to the ball fields of the park, where lighted activities at night may act as an additional impediment. It then flows under State Route 90, another busy 4-lane highway. It is unlikely many large carnivores use Woodcutter's Wash for travel.

• Table 3.1. Washes that may act as potential wildlife corridors between the Huachuca Mountains and San Pedro River, listed in order of suitability based on the total impedance score. Numbers within the columns represent the total number of cells within a 300 m x 300 m grid that touched a 100 m buffer placed along each wash. Distance is from 1 km inside the woodland interface to the San Pedro River. Values for Babocomari Wash were calculated from the Turkey Creek drainage. Cell values are multiplied by weights at the bottom of the column, and summed for the Total Urban and Total Road cells. Total Impedance is the sum of Distance, Total Urban, and Total Road columns for each row. Using Carr Wash as an example: Distance + Total Urban + Total Road = (18.2) + (24x2 + 5x4 + 0x8 + 0x16) + (28x1 + 4x3 + 0x5 + 1x6) = 18.2 + 68 + 46 = 132.2.

		Urban cells					**Road cells**					
Wash	**Distance Km**	**Low**	**Mod**	**High**	**Very High**	**Total Urban**	**Dirt**	**2-lane**	**4-lane bridge**	**4-lane box**	**Total Road**	**Total Impedance**
Memorial	11.8	0	0	0	0	0	8	1	0	0	11	22.6
Hunter	15.1	18	1	0	0	40	14	3	0	1	29	84.1
Carr	18.2	24	5	0	0	68	28	4	0	1	46	132.2
Miller	15.8	28	10	2	0	112	18	8	0	1	48	175.8
Ramsey	17.9	25	9	8	1	166	12	24	0	1	90	273.9
Slaughterhouse	32.3	0	27	2	5	204	26	7	1	0	52	288.3
Blacktail	32.4	0	27	2	5	204	26	7	1	0	52	288.4
Babocomari	43.9	0	25	2	5	196	26	6	1	0	49	288.9
Garden	22.8	2	0	1	14	236	7	12	0	1	49	307.8
Huachuca	34.2	0	25	6	7	260	9	6	1	0	32	326.2
Soldier’s	35.8	0	0	6	16	304	9	18	0	2	75	414.8
Woodcutter’s	25.4	0	0	0	28	448	0	13	0	3	57	530.4
Weights		**2**	**4**	**8**	**16**		**1**	**3**	**5**	**6**		

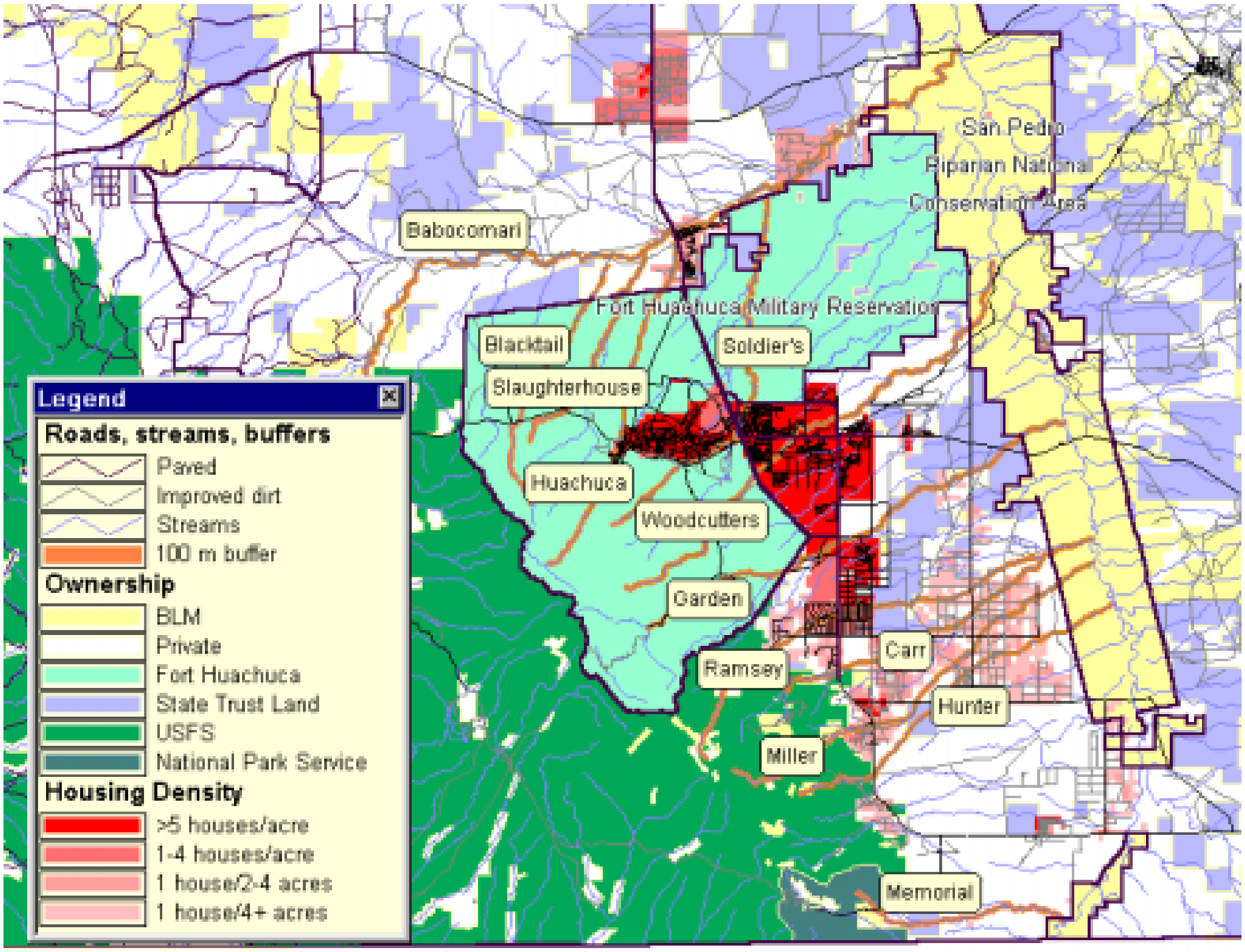


• Figure 3.1. Potential wash corridors relative to vegetation and housing density between the Huachuca Mountains and San Pedro River. Housing density from land cover maps and county 911 addresses.

The five most suitable washes for potential wildlife corridors lie mostly on private and state trust land, and are thus highly susceptible to development (Figure 3.2). Although Blacktail, Slaughterhouse, Huachuca and Soldier's washes lie primarily on Fort Huachuca, and are thus protected, they all flow into the Babocomari drainage, which is mostly private and state trust land.

Discussion

The corridor model provided an objective way to rank washes for their potential value as wildlife corridors; similar methods were used to identify linkages for grizzlies in Montana (Walker and Craighead, 1997) and statewide wildlife linkages in Florida (Hoctor et al., 2000). However, weights assigned here to urban and road categories were arbitrary, and rankings were quite sensitive to weights. Ideally, a model such as this would be field tested to develop and qualify the weightings. Caveats aside, it may be possible to relate total impedance scores to species-specific thresholds. For example, pumas, known to be somewhat tolerant of humans, may move through corridors with impedance values of up to 300, whereas a black bear may not tolerate anything above 200. This concept may allow development of species-specific movement models, and identification of critical habitat linkages. Likewise, examination of urban, road, and distance scores for each



• Figure 3.2. Potential wash corridors relative to land ownership. Land ownership layer from 1997 (ALRIS).

potential corridor may reveal where potential problems lie. For example, a moderate to high urban score due to a large tract of moderate density housing may reflect a corridor that could result in substantial wildlife-human conflicts.

Washes draining Ash and Stump Canyons were not identified as potential corridors, due to the constraint that washes terminate within 1 km of the San Pedro River. Both of these washes move through an extensive tract of undeveloped grassland before terminating > 2 km from the river. Housing and road densities are low in this area, although the area along Palominas Road is currently under development. This may create a situation where animals following washes from the Huachucas to the San Pedro River essentially find themselves in a cul de sac, with a path that ends and the remaining distance to the river blocked by houses. This creates a very undesirable situation, with a high potential for negative wildlife-human conflict, as bears, pumas, bobcats, or coatis try to negotiate human neighborhoods to get to the river.

Previous attempts to identify corridors or linkages identified large patches of habitats connected by remnants of the same habitat (Brooker et al., 1999; Walker and Craighead, 1997; Sorrell, 1999). The sky islands, including the Huachuca Mountains, are naturally isolated. Animals leaving the Huachuca Mountains to the south, east, or north leave the woodland to travel through grassland and desert scrub. The cottonwood-willow gallery forests along the San Pedro also differ from the woodland of the sky islands; it is probable that the San Pedro represents an oasis for most pumas, black bears and coatis moving between nearby mountain areas. Animals with strong affinities for woodland habitats may want to minimize travel in more open habitats, or choose routes with more cover (Soulé, 1991). It was not possible to incorporate cover as a variable in the model due to lack of fine-enough data. Attempts to validate the model by field testing should also include measurements of cover.

Studies of mammalian dispersal have found that, in general, males are the primary dispersers, whereas females seldom disperse far from their natal ranges (Harrison, 1992; Van Vuren, 1998). Median dispersal distances for black bears are 26 km, and pumas 66 km (Van Vuren, 1998), indicating that the distance between the San Pedro River and the Huachuca Mountains is within dispersal distances for these species. Little has been published about dispersal distances in coatis; indeed one study suggested that coatis do not disperse > 1 home range away from their natal range (Gompper et al., 1998). For animals moving long distances between areas of suitable habitat, the presence of oases may greatly extend their possible dispersal distances.

The results of the tracking study (Chapter 2) provide some support for the model. No tracks of pumas, black bears, or coatis were found on the Palominas route, which lies at the bottom of Memorial Wash. However, residents report observations of all three species in recent years and coatis were observed there in June 2000. For the stretch of river between Hereford and San Pedro House, where Hunter, Carr, Miller, and Ramsey Washes meet the San Pedro River, puma tracks were recorded, but no signs of coati or black bear were found. However, both puma and coati tracks were found near Fairbank, near the confluence of the Babocomari and the San Pedro Rivers. Black bear sign was observed near Fairbank a couple of years ago (H. Shaw, pers. comm.). Puma tracks found on the north boundary of Fort Huachuca near Antelope Pond may represent animal(s) moving between the Huachucas and the Babocomari River. However, several potentially confounding factors should be considered:

- Once these species arrive at the San Pedro River, they quickly move up or downstream, or out of the area;
- Related to above, the increased number of illegal immigrants between the international border and San Pedro House may displace the animals to other parts of the river;
- Little or no movement is actually occurring between the Huachuca Mountains and the San Pedro River. Sign detected may have come from relict populations or animals that originated from other places.

Harris and Ruther (2000) studied ecological characteristics of washes connecting the Huachuca Mountains to the San Pedro River. They ranked washes based on vegetation types and surface water. Garden, Woodcutter's, and Ramsey Canyon ranked high in their measure of ecological value, although they identified anthropogenic disturbance in each wash. Washes with surface water and vegetation complexity may be valuable attributes for birds, herpetofauna, small mammals, and invertebrates, and may act as genetic plant corridors, but not necessarily as movement corridors for larger mammals. Comparison of the results of this study to the one conducted by Harris and Ruther (2000) highlights the need to ask specific questions when considering identifying and implementing corridors and linkages for wildlife (Soulé, 1991).

The wash draining the east slope of Coronado National Memorial represents the best potential conduit for wildlife, although residents along the San Pedro River south of Palominas occasionally report conflicts with bears. All other washes have the potential for significant human-wildlife conflict, which will only increase as housing density increases in the unincorporated areas of Sierra Vista, Huachuca City, and Whetstone. The west slope of the Huachucas is less developed and has more wooded cover, and presents better opportunities for wildlife movements to the Patagonia and Santa Rita Mountains. Likewise, movement between the San Pedro and the Mule and Dragoon Mountains in the U.S. and the Sierra San José in Mexico is less impeded than that between the Huachucas and the San Pedro River.

Proposed Ecological Linkages

The corridor model identified three areas suitable for consideration as ecological linkages: Memorial Wash, Hunter Wash and the Babocomari River (Fig. 3.3). I refer to them as ecological, rather than biological, linkages, because their added width is meant to help preserve ecological processes, including hydrology and vegetation dynamics in addition to acting as a movement corridor. I propose linkages along these washes with the following design:

- A 200 m core area along each wash. The width is necessary to preserve long-term integrity of the wash, and reduce human-wildlife conflicts. Within this core area, the washes should be preserved as wildlife habitat, with no new housing or industrial developments, no new roads, and the only vegetation changes to include possible restoration. Recreational use, such as foot, bike, or horse trails, or picnic areas, should be limited to daytime use only. Emphasis should be on maintaining cover (mesquite, cottonwood-willow) along the washes.
- Surrounding the core area is a 1000 m buffer (bringing the width of the linkage to 1200 m). Minimal anthropogenic changes, such as low-density housing, can occur within the buffer, but heavy industry, commercial activity, or dense housing areas should be avoided. Some restrictions on vegetation clearing and alteration may be necessary. Where possible, box culverts should be replaced by highway overpasses. This buffer serves to minimize edge effects, disturbance to wildlife, and wildlife-human conflicts. The additional width also incorporates some adjacent washes (e.g., portions of Miller Wash are included in the proposed Hunter Wash linkage).

In this case, the proposed linkages will help preserve some ecosystem processes, while providing a movement corridor for large mammals. Because development is slated for all three areas, they all should be considered high priority for protection efforts. Both the proposed Hunter Wash linkage and the Babocomari linkage already have substantial housing developments within the core and buffer areas. The proposed Palominas linkage has the least impedance, and should receive highest priority. In addition, the area south of the border, encompassing Montezuma Wash to the San Pedro River, may also be important for wildlife moving between the Huachucas and San Pedro. This area should be protected as well, including minimizing disturbance due to Border enforcement activities.

The linkages are vulnerable to natural disturbance, such as fire or flood, which may affect their suitability as corridors in the short- or long-term. The vulnerability of the linkages to stochastic events could be reduced by greater redundancy, that is, designating more corridors or linkages for protection. However, the lack of other suitable areas, which do not bring wildlife into close human contact, emphasizes the importance of protecting the proposed Babocomari, Hunter Wash, and Palominas linkages for wildlife movement.

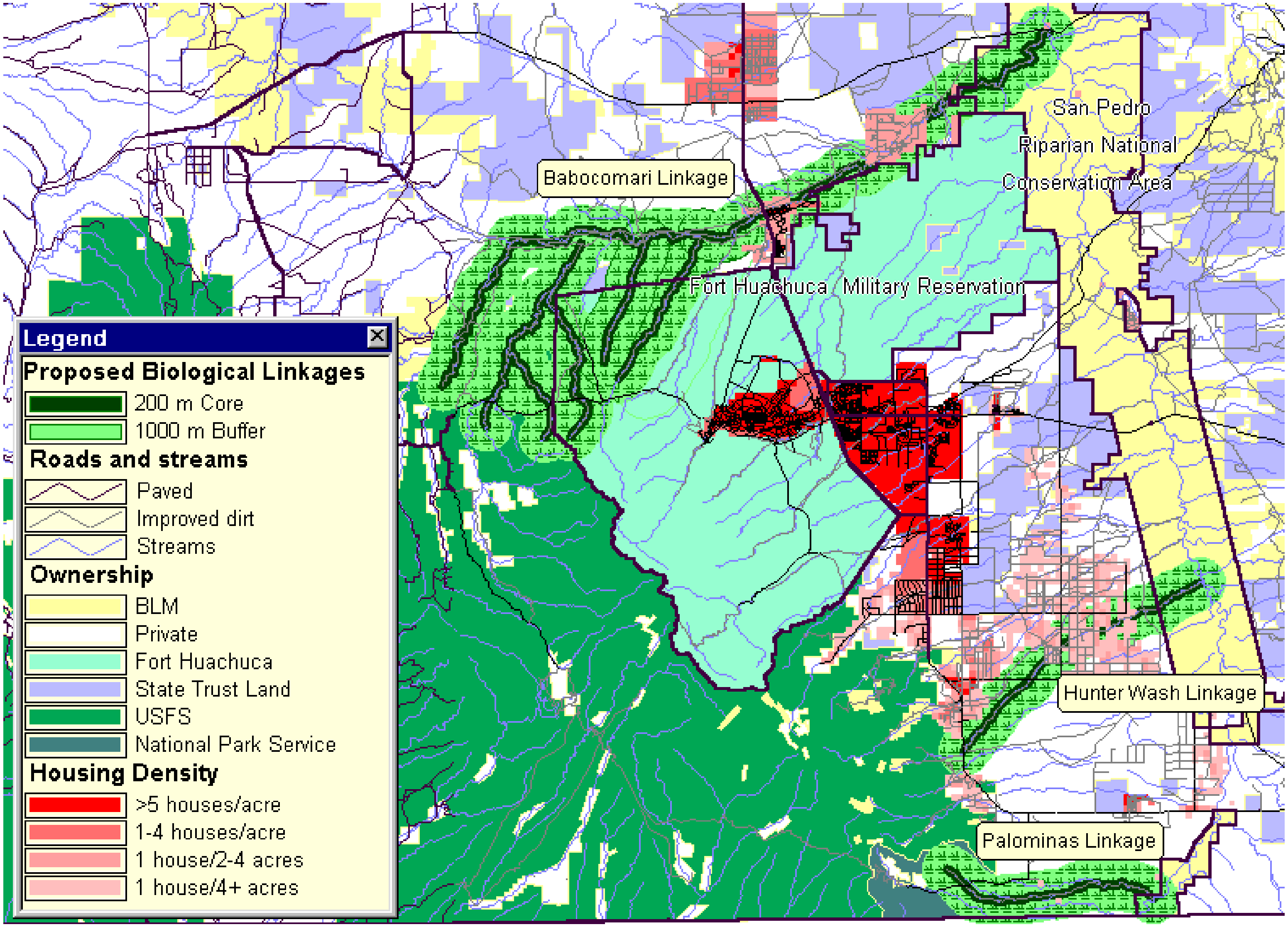
The San Pedro River provides high quality habitat for many species of carnivores, and likely acts as an oasis for others. Although exact movement corridors between the Huachuca Mountains and San Pedro River could not be identified, the model identified potential corridors. Further study is needed to validate or test the model. Regarding Florida's Ecological Network plan, Hoctor et al., (2000) stated:

> There will always be the option to sever linkages in the future if necessary, but the opportunity to protect existing landscape linkages or to restore them will diminish rapidly as Florida's human population continues to grow." (P, 998).

This comment applies to Arizona as well.

Acknowledgments

This project was funded by The Nature Conservancy, through a Rodney Johnson/Katherine Ordway Stewardship Endowment, and the Fort Huachuca Wildlife Office. My sincere thanks to Holly Richter and Sheridan Stone for their interest and support for the project, assistance in obtaining funding, and comments on the manuscript. I thank also Harley Shaw for inspiring the tracking study; Marty Tuegel for field assistance, help in obtaining GIS layers, and creative discussions; John DiBari for GIS advice, and Scott Barrett at the Harvard Graduate School of Design for providing GIS layers and advice.



• Figure 3.3. Proposed ecological linkages between the Huachuca Mountains and San Pedro River. Linkages are designed to promote the long-term integrity of potential movement corridors for wildlife and include a 200 m core area and 1000 m buffer.

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Appendix: Common and scientific names of species presented in the text.

Common Name	**Scientific Name**	**Mexican Name**
Coyote	*Canis latrans*	Coyote
Kit fox	*Vulpes macrotis*	Zorrito norteño
Grey fox	*Urocyon cinereoargenteus*	Zorro gris
Mexican wolf	*Canis lupus baileyi*	Lobo
Coati	*Nasua narica*	Coatí
Raccoon	*Procyon lotor*	Mapeche
Ringtail	*Bassariscus astutus*	Cacomixtle
Puma	*Puma concolor*	Puma
Bobcat	*Lynx rufus*	Gato montés
Jaguar	*Panthera onca*	Tigré
Ocelot	*Leopardus pardalis*	Ocelote
Hooded skunk	*Mephitis macroura*	Zorillo rayado
Striped skunk	*Mephitis mephitis*	Zorillo listado
Spotted skunk	*Spilogale gracilis*	Zorillo pinto
Hog-nosed skunk	*Conepatus mesoleucus*	Zorillo cadeno
Badger	*Taxidea taxus*	Tejón
Long-tailed weasel	*Mustela frenata*	Comadreja
Black bear	*Ursus americanus*	Oso negro
Mexican grizzly	*Ursus arctos*	Oso gris
Javelina	*Pecari tajacu*	Jabalí
Deer	*Odocoileus hemionus & O. virginianus*	Venado buro y venado cola blanca
Cattle	*Bos taurus*	Ganado