# A SPATIAL MODEL OF POTENTIAL JAGUAR HABITAT IN ARIZONA

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*Abstract:* The jaguar (*Panthera onca*) is an endangered species that occasionally visits the southwestern United States from Mexico. The number of jaguar sightings per decade has declined over the last 100 years in Arizona, USA, raising conservation concerns for the species at a local and national level. In 1997, state, federal, and local governments with land-management responsibilities agreed to characterize and identify potential jaguar habitat in Arizona and New Mexico. Specifically, the objectives of our analysis were 2-fold: (1) characterize potential jaguar habitat in Arizona from historic sighting records and (2) create a statewide habitat suitability map. We used a Geographic Information System (GIS) to characterize potential jaguar habitat by overlaying historic jaguar sightings (25) on landscape and habitat features believed important (e.g., vegetation biomes and series, elevation, terrain ruggedness, proximity to perennial or intermittent water sources, human density). The amount of Arizona (%) identified as potential jaguar habitat ranged from 21% to 30% depending on the input variables. Most jaguar sightings were in scrub grasslands between 1,220 and 1,829-m elevation in southeastern Arizona, in intermediately to extremely rugged terrain, and within 10 km of a water source. Conservation efforts should focus on protecting the most suitable jaguar habitat in southeastern Arizona (i.e., Santa Cruz, Pima, Cochise, Pinal, Graham counties), travel corridors within and outside Arizona, and jaguar habitat in the Sierra Madres of Sonora, Mexico.

***JOURNAL OF WILDLIFE MANAGEMENT 69(3):1024–1033; 2005***

*Key words:* Arizona, *Panthera onca*, conservation, Geographic Information System, GIS, habitat selection, landscape, neighborhood analysis, predictive modeling, jaguar.

Jaguars have been noted for their adaptability to a wide variety of environmental conditions (Rabinowitz and Nottingham 1986, Seymour 1989). Habitat studies in the core part of jaguar range indicate a close association with water, dense cover (Schaller and Crawshaw 1980, Quigley and Crawshaw 1992), sufficient prey (Seymour 1989, Swank and Teer 1989), and an avoidance of highly disturbed areas (Quigley and Crawshaw 1992). Jaguars have been found from sea level to 3,800 m (Tewes and Schmidly 1987) but rarely over 1,000 m (Seymour 1989). They have also been found in a wide variety of vegetation communities from tropical rainforest and flooded grassland mosaics to Madrean evergreen woodland, semi-desert grasslands, and wooded canyons of the Sonoran Desert (Rabinowitz 1999, Brown and Lopez Gonzales 2001).

Jaguars are opportunistic feeders with more than 85 prey species reported in their diet (Seymour 1989), including mammals, reptiles, and birds. Primary prey items are diurnal, terrestrial mammals with a body mass >1 kg (Seymour 1989). In the southwestern United States, potential prey species include collared peccary (*Tayassu tajacu*), white tailed deer (*Odocoileus virginianus*), mule deer (*Odocoileus hemionus*), coatis (*Nasua nasua*), skunk (*Mephitis* spp., *Spilogale gracilis*), raccoon (*Procyon lotor*), jack rabbit (*Lepus* spp.), domestic livestock, and horses.

The southwestern United States and Sonora, Mexico are at the extreme northern limits of the jaguar's range that extends primarily from northern Argentina to central Mexico (Swank and Teer 1989, Sanderson et al. 2002). Over the last century, the jaguar's range has been reduced to approximately 46% of its historic (pre-1900) range due to hunting pressure and habitat loss, especially in the southern United States, northern Mexico, northern Brazil, and southern Argentina (Swank and Teer 1989, Sanderson et al. 2002). Jaguars have been documented occasionally in the southwestern United States since 1900, but the number of sightings per decade has declined over the last 100 years (Brown 1983). In 1996, there were 2 jaguars photographed in the mountains of southeastern Arizona (Glenn 1996, Childs 1998), raising conservation concerns for the species at local and national levels and prompting the federal government to list the jaguar as endangered (Federal Register 1997).

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Representatives of local, state, and federal governments with land-management responsibilities in Arizona and New Mexico signed a Memorandum of Agreement (MOA) to implement a Conservation Agreement for jaguar (Johnson and Van Pelt 1997). One of the main objectives of the Conservation Agreement was to identify potential jaguar habitat in Arizona and New Mexico to help focus conservation efforts and identify opportunities for jaguar habitat management. Signatories of the MOA established numerous teams, including a Jaguar Scientific Advisory Group and a Habitat Subcommittee. Arizona was considered the best starting point for mapping potential jaguar habitat in the United States because it contained the greatest number of jaguar reports north of Mexico during the 20th century (Rabinowitz 1999). Specifically, the objectives of our analysis were twofold: (1) characterize potential jaguar habitat in Arizona from historic sighting records and (2) create a statewide habitat suitability map.

## METHODS

### Modeling Approach

In order to map potential jaguar habitat in Arizona, we first had to identify and characterize it. The Jaguar Scientific Advisory Group recommended not using prey density as a criterion for jaguar habitat because wildlife agencies can manage wild game populations to increase in numbers. They also recommended excluding areas with high human density or areas with anthropogenic impacts because jaguars are secretive animals and tend to avoid highly disturbed areas (Quigley and Crawshaw 1992). Therefore, we masked from our analysis areas within city boundaries, higher density rural areas visible on Thematic Mapper (TM) satellite imagery (30-m resolution), and agricultural areas. We obtained the outlines of cities and towns from the Arizona State Land Department and agricultural outlines from TM imagery (Valencia et al. 1993).

The Jaguar Scientific Advisory Group provided us with a list of potential habitat variables to help steer our analysis, but most of the literature pertained to jaguar habitat located far to the south of Arizona in areas with dissimilar climates and biomes. Our task was complicated because the historic sighting records contained widely varying spatial error (1–30 km), so we had to consider the possibility that some of the biomes associated with jaguars might not be correct. Another problem was the lack of information regarding the amount of time jaguars occupied an area before capture or sighting, making it difficult for us to distinguish a travel corridor from actual jaguar habitat.

To address these concerns, we screened the sighting records for accuracy and created 3 different habitat suitability models by altering the input variables (habitat or landscape features). We defined habitat suitability the same as potential jaguar habitat (i.e., any area containing the features associated with jaguar sites as determined from our GIS [ESRI, Redlands, California, USA] analysis) or meeting the criteria supplied by the Jaguar Scientific Advisory Group. Our first habitat suitability model was the most conservative because we only used input variables found to be important in a GIS analysis. Our second model examined the sensitivity of the first model by relaxing some of the input criteria, allowing us to examine patch connectivity and travel corridors. Our third model was the most general, developed to include additional biomes that might have been missed in our GIS analysis due to spatial error or from errors of omission related to observational data.

We characterized potential jaguar habitat by overlaying historic jaguar sightings and coarse-scaled habitat features we thought were important. We took a landscape approach by focusing on coarse-scaled habitat features because the jaguar sites had highly variable positional error, making them insufficient for a fine-scaled analysis. Coarse-scaled habitat features considered important included vegetation biomes (ecosystems) and series (defined by dominant or characteristic species), elevation and terrain ruggedness, proximity to perennial or intermittent water sources (i.e., streams, rivers, lakes, or springs), and human density. We used a GIS to create, manage and analyze the data, characterize broad-scale habitat features where jaguars were observed, and map potential jaguar habitat.

### Historical Database and Mapping

We examined 57 sighting records where jaguars were supposedly sighted or killed (Appendix 1). The quality and reliability of the sighting records varied greatly, with some dating back 100 years. To create a useful database for analysis, we sorted records into 3 classes based upon their reliability: (1) physical evidence ($n = 24$), (2) firsthand account obtained by a reliable source (interviewed by a game warden or scientist [$n = 7$]), or (3) secondhand account, which we considered unreliable ($n = 26$). We also rated records according to their site description (Appendix 1) as excellent ($n = 16$), good ($n = 5$), fair ($n = 4$), or poor ($n = 32$)

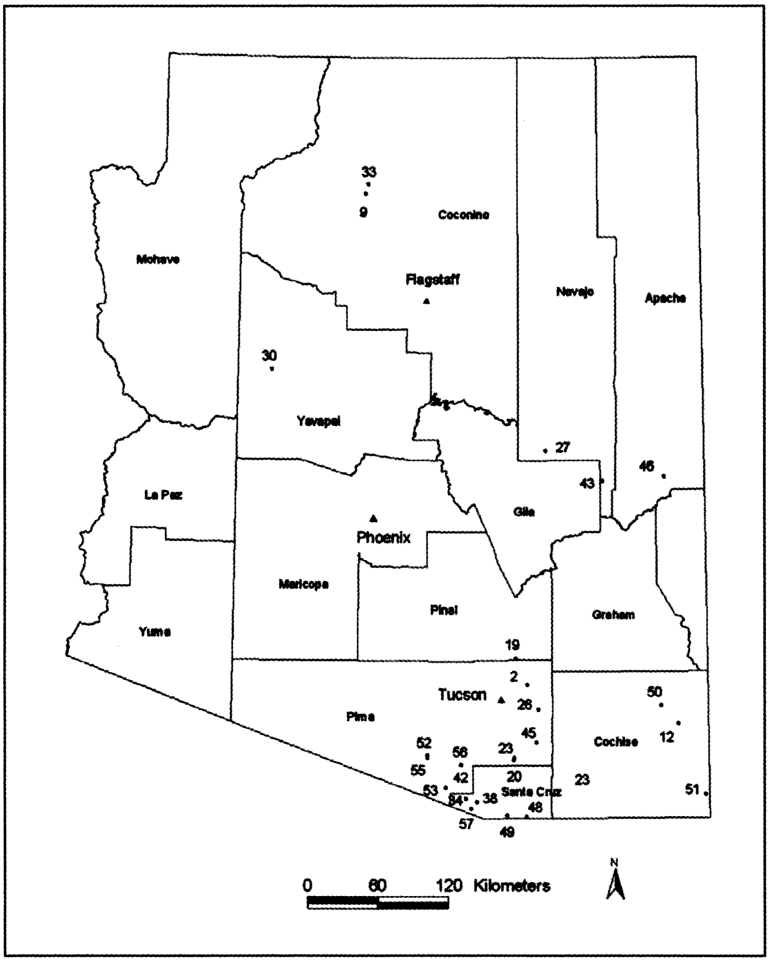


Fig. 1. A map displaying the 25 jaguar sighting records we used. We only used sites with physical evidence of jaguars (body, skin, or photographs) or first-hand accounts of jaguar sightings that were obtained and accepted by a reliable source (game warden or scientist) and had an acceptable positional accuracy (<8 km; Appendix 1).

because some reliable sightings could not be accurately mapped. We considered sites that could be mapped to within 1.6 km of their estimated sighting location excellent, 1.7–5 km good, 5.1–8 km fair, and >8 km poor. An excellent-rated site contained specific information, such as the junction of 2 creeks; a good-rated site description might say 3 km from the creek junction, but without necessarily a direction; while a fair-rated site description referenced a specific feature, like a creek junction or summit, but without a distance to the feature. Last, poor-rated site descriptions contained very broad locality information, like a mountain range.

To improve our mapping effort, we plotted jaguar sites with a GIS that displayed digital topographic maps, satellite imagery, hydrography, and shaded relief maps to visualize terrain. To reduce positional error and create the most specific habitat suitability model, we used only the most reliable and spatially accurate records ($n = 25$, Fig. 1). We considered sighting records that contained no physical evidence, were derived from secondhand accounts, or had spatial errors >8 km, insufficient for our spatial analysis. This does not mean that jaguars did not occur at some of the locations we labeled as poor or that jaguars did not visit other locations in Arizona. Hence, all spatial analyses and references to jaguar sightings refer only to the 25 sighting records we analyzed.

## GIS Analysis

To calculate the distance between jaguar sites and water, we created 2 grids that contained the distance of each grid cell to perennial or intermittent waters (Fig. 2A) and springs (Fig. 2B). We calculated distance to water from the shortest path possible that was usually less than the actual ground distance. We included intermittent water sources because they were important habitat features through much of the year in Arizona. To examine the relationship between jaguars and elevation, we overlaid sighting records and Digital Elevation Model (DEM) data (Fig. 2C). We sorted the DEM data (30-m resolution) into 609-m (2,000-ft) elevation zones to more clearly identify patterns in jaguar distribution.

To examine the relationship between jaguars and landscape roughness, we calculated a terrain ruggedness index (TRI; Riley et al. 1999) for the whole state of Arizona (Fig. 2D). The TRI measures slopes in all directions of each cell examined

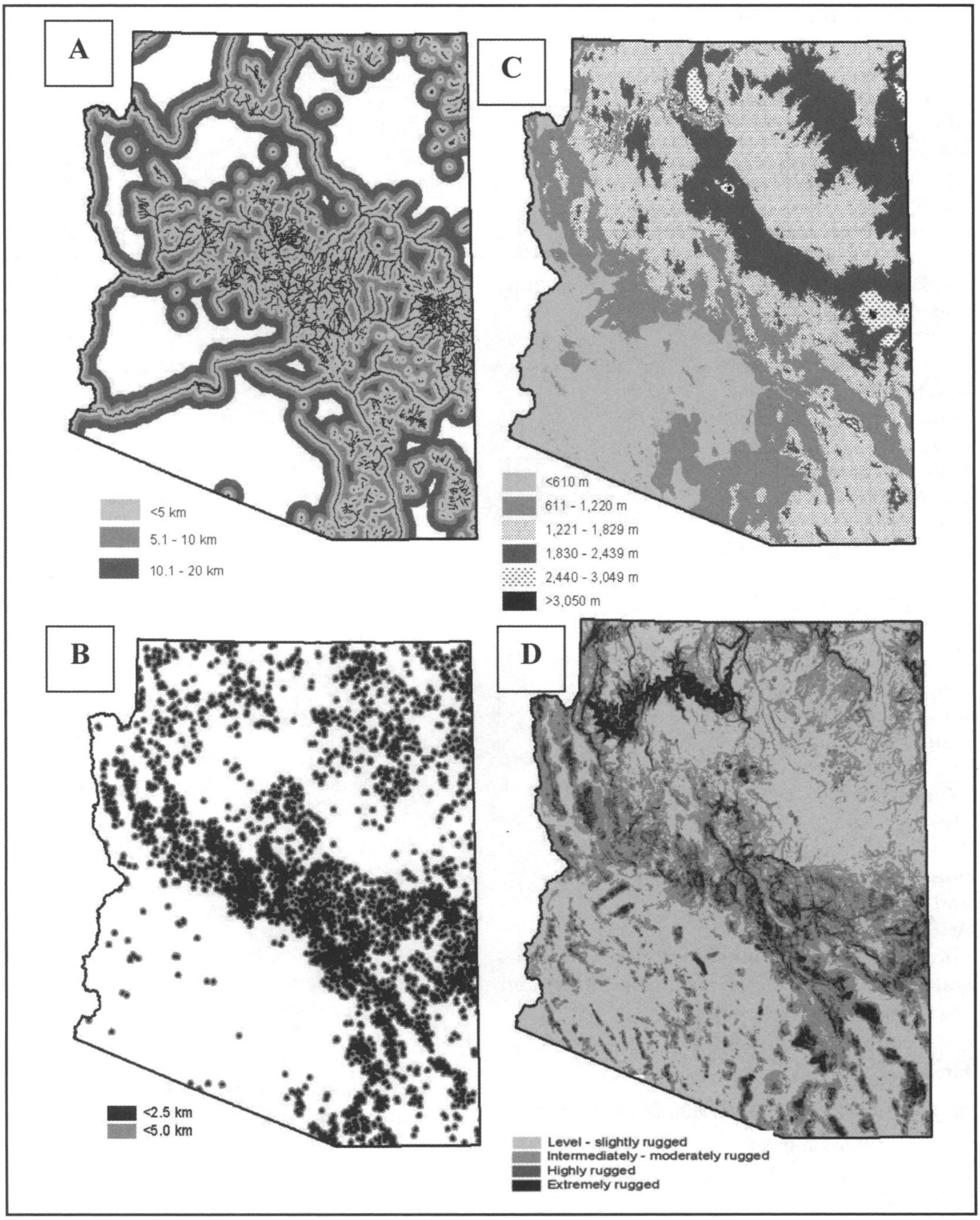


Fig. 2. Proximity to perennial or intermittent waters (A) and springs (B), elevation zones (609-m bands [C]), and a terrain ruggedness index map (D).

and thereby provides an index of overall ruggedness in a neighborhood, which is more descriptive than a simple slope surface. We calculated TRI in a 3-step process: (1) we mosaiced 1,986 30-m resolution DEMs together, (2) we aggregated (clustered and averaged) DEM data into 1-km$^2$ cells, and (3) we calculated the sum difference in elevation between each cell and its surrounding neighbor cells. We divided the TRI data into 7 classes according to their relative roughness: level, nearly level, slightly rugged, intermediately rugged, moderately rugged, highly rugged, and extremely rugged. We overlaid jaguar data with TRI data for examination.

To characterize vegetation biomes and series occupied by jaguars, we overlaid sighting records and Arizona GAP (AZGAP) data (Halvorson and Kunzmann 2000) that had 82% overall accuracy at the biome level and 68% at the series level. The AZGAP is based on the Brown, Lowe, and Pase (BLP) system (Brown et al. 1980, Brown 1994) that contains 8 levels of organization. The AZGAP accuracy assessment was complicated by many factors including spatial scale, fuzzy boundaries, and classification ranks (Kunzmann et al. 1998). However, the AZGAP cover contained the most detailed vegetation and land cover data of Arizona and provided an unprecedented opportunity to explore landscape-scale relationships between jaguar sightings and vegetation biomes and series.

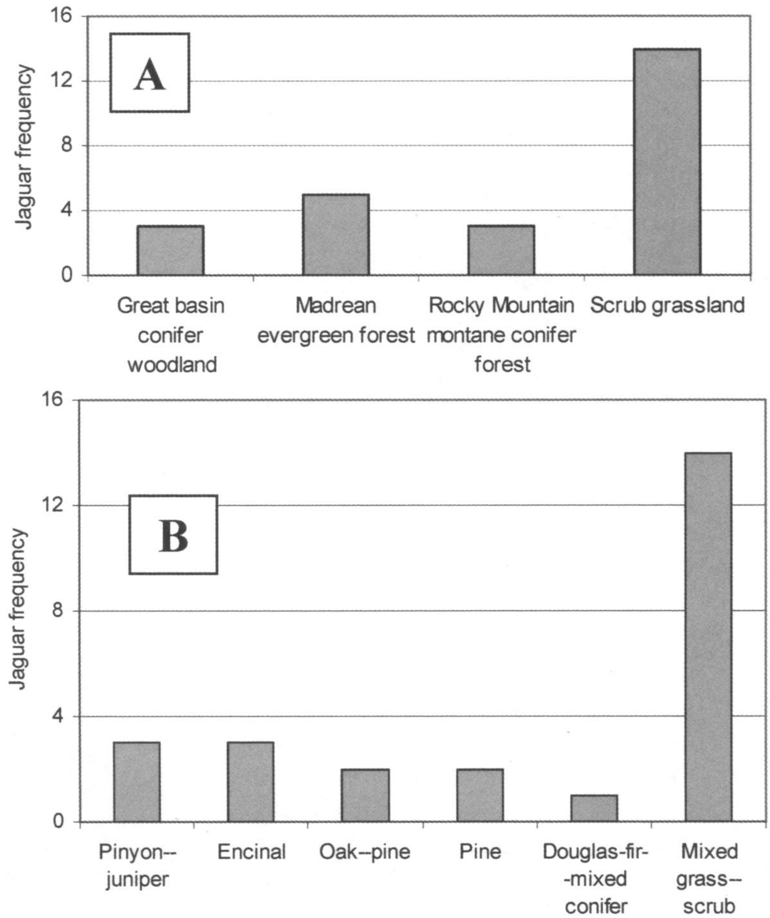

Fig. 3. Frequency of jaguar sightings in biomes (A) and vegetation series (B).

## RESULTS

### Jaguar Occurrence and Distribution Patterns

The distribution of jaguar sightings was clumped in southeastern Arizona and scattered in central and northwestern Arizona (Fig. 1). A geographic region surrounding Tucson (100-km radius) contained 54% ($n = 16$) of all jaguar sightings, including 1 as recent as 2001, and it is comprised of the following mountain ranges and associated grasslands: Santa Catalinas, Rincons, Santa Ritas, Baboquivaris, Tortolitas, Patagonias, Bartolos, Sierritas, and Atascosa Mountains. A secondary concentration near Douglas, comprised of the Chiricahua, Peloncillo, and Dos Cabezas Mountains, contained 12% ($n = 3$) of the historic sightings. There have also been 4 jaguars sighted in southeastern Arizona since 1995 (no. 51, no. 52, no. 56, no. 57). Twenty-four percent ($n = 6$) of jaguar sightings were dispersed along the Mogollon Rim from New Mexico to the Grand Canyon and south to the Prescott area.

### GIS Overlays

One hundred percent ($n = 25$) of the sighting records were observed in 4 biomes (Fig. 3A). Of these, 56% were observed in scrub grasslands of southeastern Arizona, 20% in Madrean evergreen forest, 12% in Rocky Mountain montane conifer forest, and 12% in Great Basin conifer woodland. At the vegetation series level (Fig. 3B), jaguars were observed 4.7 times more often in mixed grass-scrub than any other community. Related to water, 64% of jaguar records occurred within 5 km of a perennial or intermittent creek or river, 76% within 10 km, and 84% within 20 km. Furthermore, 80% of jaguar records occurred within 2.5 km of a spring, and 96% occurred within 5 km. When we combined springs, rivers, and creeks, 100% of the sighting records were within 10 km of a water source. Sixty percent of jaguars were observed between 1,220- and 1,829-m elevation (Fig. 4A), largely in the scrub grassland biome of southeastern Arizona. The remaining jaguar sightings were between 1,036 and 2,743 m. With respect to topography, 92% of jaguar sightings occurred in intermediately rugged to extremely rugged terrain (Fig. 4B), with the remainder (8%) in nearly level terrain.

### Habitat Suitability Mapping

Four biomes contained 100% ($n = 25$) of jaguar sites (Fig. 3A) and encompassed 37% of the state (108,222 km$^2$). The suitability envelope decreased to 21% when we excluded areas >10 km from perennial or intermittent waters and gently sloped areas (TRI < 4; Model A, Fig. 5). After considering the experimental nature and unproven significance of the TRI variable that might exclude biologically important areas or mask travel corridors, we reran the model without the TRI filter. This increased the potential habitat envelope to 28.9% of the state (Model B, Fig. 5). Omitting the TRI filter reduced the patchiness of Model A and resulted in the identification of potential travel corridors between areas identified in Model A.

To compare our results to a more liberal model, we reran the model a third time (Model C, Fig. 5) to include areas that might have been visited by jaguars but missed in our earlier analysis because of spatial error. We added the Madrean montane conifer forest biome because it contained vegetation series commonly found in upper elevations of Sky Islands of southeastern Arizona. We also added 4 riparian biomes found in Arizona because jaguars might use them for travel corridors. The addition of these 5 biomes only marginally increased the amount of potential jaguar habitat (29.6% of the state).

The area with the most jaguar sightings was located in southeastern Arizona (Fig. 5) in Santa Cruz, Pima, Cochise, Pinal, and Graham counties. Potential habitat in that area loosely resembled an inverted V with the southern end separated by a swath of agricultural and developed land and few perennial or intermittent waters. When we did not apply the TRI filter, habitat corridors formed to the south and north of the Cochise and Graham County boundary. Another large patch of potential jaguar habitat extended northwestward from the Mogollon and

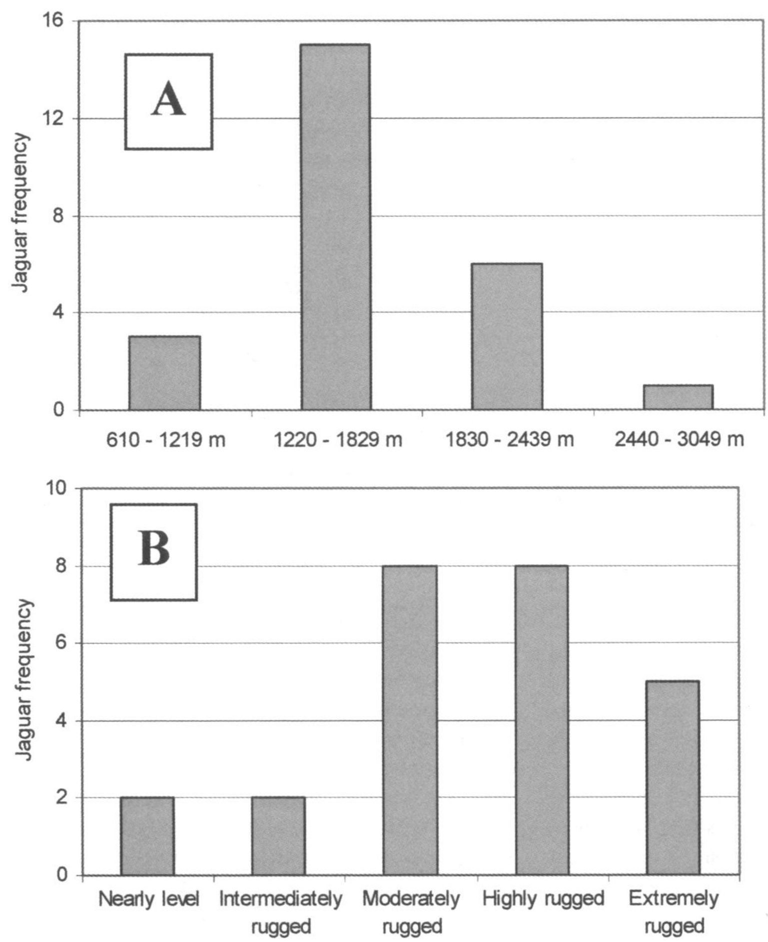


Fig. 4. Frequency of jaguar sightings within the 609-m elevation zones (A) and within 5 of the 7 terrain ruggedness index classes (B).

Gila Mountains of New Mexico, across the Mogollon Rim to the Williams-Flagstaff area. Without the TRI filter, this area just barely connected with another, smaller patch that extended south to the Prescott area. Although these patches contained approximately 25% of the historic jaguar observations, no jaguars were recorded from this area since 1964. The northern area was disconnected from the 2 habitat patches to the south by a broad band of unsuitable land approximately 17 km wide that encompassed the Gila River Valley near the city of Safford.

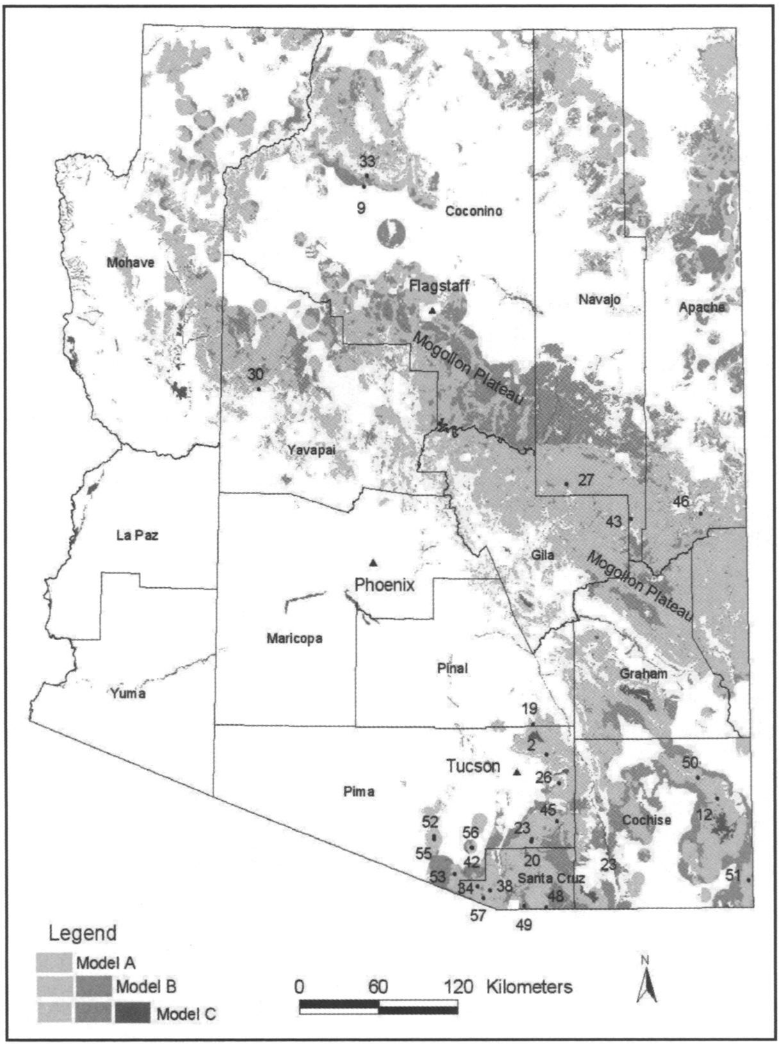


Fig. 5. We identified potential jaguar habitat in Arizona in 3 separate model runs that used different input variables (habitat features) or criteria (roughness filter). Model A was the most spatially conservative model, with just 4 biomes and a terrain ruggedness index (TRI) filter applied; we excluded level and slightly rugged areas. Model B was identical to Model A but without a TRI filter applied. Model C was similar to Model B but included 5 additional biomes (Madrean montane conifer forest and 4 riparian biomes). All 3 models excluded areas that were >10 km from water.

## DISCUSSION

### Coarse-scaled Habitat Associations

We found that most jaguar sightings occurred between 1,220 and 1,829 m, an elevation band in which scrub grasslands were common. The apparent preference of jaguars for scrub grasslands may actually reflect the use of travel corridors from the Sierra Madres of Mexico into southeastern Arizona rather than a preferred vegetation type, or perhaps jaguars were just more visible in open grasslands. Some problems with observational data are that animals will more often be sighted in the open, especially in the daytime and in areas where more observers (e.g., ranchers, hikers) are located. All jaguar sightings in our database had occurred in the daytime and almost always in less dense vegetation. However, there were no jaguar sightings in the lower elevation deserts, which are very open and exposed; this supports the idea that elevation and biomes were important selective factors in our analysis regardless of the limitations of observational data.

There was a strong association between jaguar sightings and distance to water, with all sites falling within 10 km of a perennial or intermittent water source. While we calculated these proximities as straight line (Euclidean) distances—and in mountainous terrain, they could have been considerably further—the relatively close proximity of jaguars to water potentially explains much about their distribution pattern in Arizona. River valleys might provide travel corridors for jaguars, along with higher prey densities, cooler air, and denser vegetation than surrounding habitats.

We found an association between jaguar occurrence and terrain ruggedness that was also observed in Mexico (Ortega-Huerta and Medley 1999) and New Mexico (Menke and Hayes 2004). As the human population in Arizona's gently sloped valleys continues to grow, jaguars might avoid these areas and stick to the more mountainous, rugged country. However, less rugged areas may serve as travel corridors between habitat patches in neighboring mountain ranges, providing that other habitat components (e.g., cover, water) are available. Perhaps the most important factor explaining jaguars' apparent preference for rugged terrain is the abundance of water in mountainous terrain of southeastern Arizona (Figs. 2A, B).

## Additional Research Needs

The jaguar habitat suitability map (Fig. 5) presents a coarse outline of potential jaguar habitat in Arizona but little in the way of fine-scale habitat needs, and it should be viewed with caution until more specific habitat-use data becomes available. We constructed the 3 habitat models from observational data, and there is no accuracy currently associated with the habitat map. We would have benefited by sorting out the independent and combined influences of landscape and habitat variables on jaguar occurrence within a multivariate-modeling environment, but our data were insufficient for this approach. We need to examine the habitat usage of jaguars in northern Sonora, the closest population of jaguars to Arizona, to refine and ground-truth our habitat suitability map. Furthermore, identifying the travel corridors jaguars utilize from northern Sonora into Arizona and New Mexico is imperative to our understanding of patch connectivity across state and international borders.

## MANAGEMENT IMPLICATIONS

We identified a great deal of potential jaguar habitat along the Mogollon Plateau (Fig. 5), but jaguars have not been sighted north of the Gila River Valley in 40 years, supporting our hypothesis that land use practices are limiting jaguar movement into central Arizona. Jaguar distribution patterns in the last 40 years suggest that southeastern Arizona is the most likely area for future jaguar occurrence in the United States and conservation efforts should focus on protecting potential jaguar habitat in Santa Cruz, Pima, Cochise, Pinal, and Graham counties (Fig. 6). The proposed conservation area is connected to Mexico and offers a unique opportunity for international cooperation in the management and conservation of the jaguar at the northern extent of its range.

## ACKNOWLEDGMENTS

We thank the members of the Jaguar Conservation Team's Habitat Subcommittee and the participants in the Conservation Team's Working Group for thoughtful comments and for their persistent, enthusiastic participation in this new approach to conserving jaguars. We also thank the members of the Jaguar Scientific Advisory Group

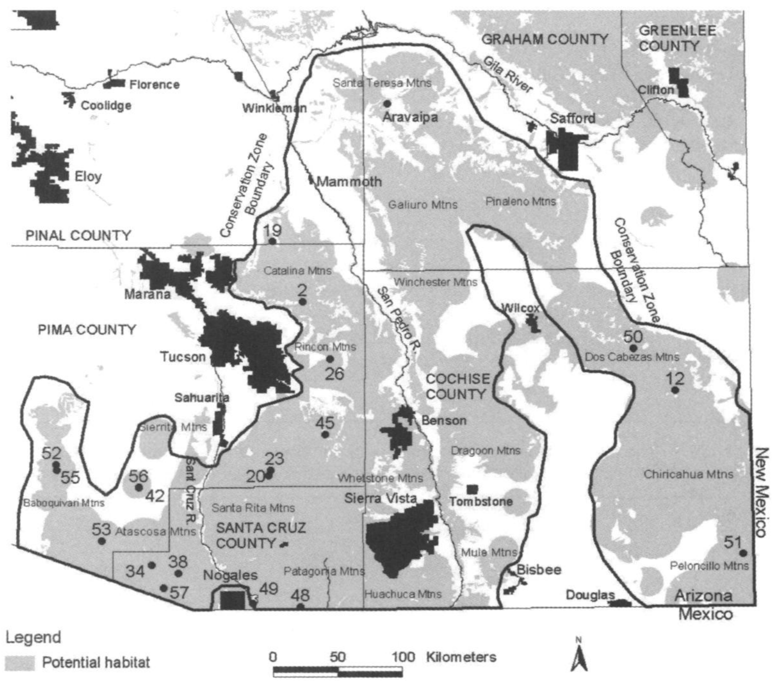


Fig. 6. We identified a potential conservation area for jaguars in southeastern Arizona from historical sighting records and ancillary information provided by the Jaguar Scientific Advisory Group. We developed 3 different habitat suitability models for jaguar, ranging from conservative to liberal. We used Model C, our most liberal spatial model, in the identification of a proposed conservation area.

for volunteering their time and expertise to help develop the habitat criteria for this model.

Funding for Arizona Game and Fish Department (AGFD) participation in this project was provided by voluntary contributions to Arizona's Nongame Wildlife Checkoff, the AGFD's Heritage Fund (Lottery Dollars Working for Wildlife), Arizona's Nongame Wildlife Checkoff, and Project W95M under the Federal Aid in Wildlife Restoration Act (Pittman-Robertson Act). In addition, many volunteers participated in the Jaguar Conservation Team and Working Group and have contributed significantly with donated time and money.

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*Associate Editor: Krausman.*

Appendix 1. The 57 sighting records examined for our Geographic Information System analysis. Information on jaguar sites was obtained from the published literature, newspaper articles, and government records.

| Code[a] | Year[b] | Cl[c] | Lc[d] | Location | Sex |
|---|---|---|---|---|---|
| 1 | 1901 | 3 | | Dos Cabezas Mountains | |
| 2* | 1902 | 1 | 2 | Redington Pass | m |
| 3 | 1902 | 3 | | Catalina Mountains | |
| 4 | 1903 | 3 | | Atascosa Mountains | |
| 5 | 1904 | 3 | | Verde River | |
| 6 | 1906 | 3 | | Chiricahua Mountains | f |
| 7 | 1907 | 3 | | Patagonia Mountains | |
| 8 | 1907 | 3 | | Mogollon Mountains | |
| 9* | 1907 | 1 | 1 | South Rim Grand Canyon | m |
| 10 | 1910 | 3 | | Chevlon Canyon | f |

*(continued on next page)*

Appendix 1. continued.

| Code[a] | Year[b] | Cl[c] | Lc[d] | Location | Sex |
|---|---|---|---|---|---|
| 11 | 1910 | 3 | | Chiricahua Mountains | f |
| 12* | 1912 | 1 | 1 | Chiricahua Mountains | |
| 13 | 1912 | 3 | | Sunset Mountain | |
| 14 | 1912 | 3 | | Bozarth Mesa | |
| 15 | 1912 | 3 | | Catalina Mountains | |
| 16 | 1912 | 3 | | Rincon Mountains | |
| 17 | 1913 | 1 | 4 | Tortolita Mountains | |
| 18 | 1913 | 3 | | Red Mountain | m |
| 19* | 1916 | 1 | 3 | Catalina Mountains | m |
| 20* | 1917 | 1 | 1 | Santa Rita Mountains | m |
| 21 | 1918 | 3 | | South Rim Grand Canyon | |
| 22 | 1918 | 3 | | Santa Rita Mountains | |
| 23* | 1919 | 1 | 1 | Santa Rita Mountains | f |
| 24 | 1920 | 2 | 4 | Rincon Mountains | |
| 25 | 1920 | 2 | 4 | Santa Rita Mountains | |
| 26* | 1922 | 1 | 3 | Rincon Valley | |
| 27* | 1924 | 1 | 3 | Mogollon Plateau | |
| 28 | 1926 | 1 | 4 | Patagonia Mountains | |
| 29 | 1926 | 1 | 4 | Atascosa Mountains | m |
| 30* | 1926 | 1 | 2 | Santa Maria Mountains | m |
| 32 | 1929 | 3 | | Sand Tank Mountains | |
| 31 | 1930 | 3 | | Chiricahua Mountains | |
| 33* | 1932 | 2 | 1 | South Rim Grand Canyon | f |
| 34* | 1933 | 2 | 1 | Atascosa Mountains | m |
| 35 | 1933 | 3 | | Sierra Estrella Mountains | |
| 36 | 1934 | 3 | | Atascosa Mountains | |
| 37 | 1939 | 3 | | Bloody Basin | |
| 38* | 1939 | 1 | 1 | Atascosa Mountains | m |
| 39 | 1940 | 3 | | White Mountains | |
| 40 | 1947 | 3 | | Atascosa Mountains | |
| 41 | 1948 | 3 | | Patagonia Mountains | m |
| 42* | 1949 | 1 | 2 | Cerro Colorado Mountains | f |
| 43* | 1957 | 1 | 2 | White River | |
| 44 | 1957 | 3 | | Red Mountain | m |
| 45* | 1961 | 1 | 1 | Empire Mountains | m |
| 46* | 1963 | 1 | 2 | White Mountains | f |
| 47 | 1964 | 1 | 4 | Black River | m |
| 48* | 1965 | 1 | 3 | Patagonia Mountains | m |
| 49* | 1971 | 1 | 1 | Santa Cruz River | m |
| 50* | 1986 | 1 | 1 | Dos Cabezas Mountains | m |
| 53* | 1988 | 2 | 1 | San Luis Mountains | |
| 54 | 1988 | 3 | | Sierrita Mountains | |
| 55* | 1993 | 2 | 1 | Baboquivari Mountains | |
| 51* | 1996 | 1 | 1 | Peloncillo Mountains | m |
| 52* | 1996 | 1 | 1 | Baboquivari Mountains | |
| 56* | 1997 | 2 | 1 | Cerro Colorado Mountains | |
| 57* | 2001 | 1 | 1 | Pajarito Mountains | m |

*Used in model development and presented in Figs. 1, 5, and 6.

[a] Site locations on Figs. 1, 5, and 6.

[b] The year jaguar was observed.

[c] Cl = Class description: 1 = physical evidence (skin, body, photograph); 2 = reliable witness (firsthand account that was obtained and accepted by an authority [game warden or scientist]); 3 = less reliable (secondhand account).

[d] Lc = Location description: 1 = excellent location description (<1.7-km accuracy); 2 = good (1.7 to 5-km accuracy); 3 = fair (5.1 to 8-km accuracy), 4 = poor (>8-km accuracy). We did not rank class 3 sites (Cl = 3) for location accuracy.