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# USE OF URBAN LANDSCAPE BY COYOTES

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Abstract—Several aspects of the ecology of coyotes (*Canis latrans*) have been studied in cities (i.e., diet, use and selection of habitat, movements), but additional knowledge will assist persons that are responsible for management of urban predators. We studied coyotes in central Tucson, Pima Co., Arizona, during November 2005–November 2006. Our objectives were to monitor radiocollared coyotes to determine size of home range, to ascertain use of habitat based on land-use categories and movements, and to describe a den of urban coyotes. Average size of home range calculated using the 95% fixed-kernel method was 26.8 ± 5.1 *SE* km$^2$ for resident coyotes. Overall, land categories used most often were washes, medium-density residential areas, and low-density residential areas. Movements were <520 m/h within land-use categories used most often during day and night (i.e., medium-density residential areas and washes) and >800 m/h in areas that were used most during the night (i.e., high-density residential and commercial areas). Coyotes were able to meet their life-history requirements in central Tucson likely due to available resources and a diversity of land-use categories, especially washes.

Resumen—Varios aspectos de la ecología de los coyotes (*Canis latrans*) han sido estudiados en las ciudades (por ejemplo, su dieta, uso y selección del hábitat, movimientos), sin embargo información adicional puede ayudar a las personas responsables del manejo de depredadores urbanos. Estudiamos a los coyotes en el área central de Tucson, condado de Pima, Arizona, desde noviembre del 2005 hasta noviembre del 2006. Nuestro objetivo fue monitorear coyotes con radio-collares para determinar el tamaño del rango del hogar, para confirmar el uso del hábitat basado en categorías de uso de tierra y movimientos, y para describir una guarida de coyotes urbanos. El tamaño promedio del rango del hogar estimado para coyotes residentes, usando el método de <<fixed-kernel>> al 95%, fue 26.8 ± 5.1 *ES* km$^2$. En general, las áreas mayormente seleccionadas fueron los arroyos secos y las áreas residenciales con densidad poblacional media y baja. Los movimientos fueron <520 m/h en las áreas que los coyotes utilizaron mayormente durante el día y la noche (por ejemplo las áreas de densidad residencial media y los arroyos secos) y >800 m/h en áreas que fueron usadas más durante la noche (por ejemplo áreas de alta densidad residencial y comercial). Los coyotes fueron capaces de suplir sus requisitos de vida en el centro de Tucson probablemente debido a los recursos disponibles y a la diversidad de categorías del uso de tierra, especialmente los arroyos secos.

Loss of habitat is a primary factor contributing to decline of wildlife populations worldwide (Ehrlich and Ehrlich, 1981), but large cities are a new ecosystem (Gill and Bonnett, 1973) where some species thrive. Predators such as coyotes (*Canis latrans*; Shargo, 1988; Atkinson and Shackleton, 1991; Grinder and Krausman, 2001), bobcats (*Lynx rufus*; George and Crooks, 2006), cougars (*Puma concolor*; Currier 1976), American black bears (*Ursus americanus*; Lyons, 2005), and smaller mammals such as red foxes (*Vulpes vulpes*; Adkins and Stott, 1998), gray foxes (*Urocyon cinereoargenteus*; Harrison, 1997), striped skunks (*Mephitis mephitis*; Rosatte et al., 1991), and raccoons (*Procyon lotor*; Riley et al., 1998) have found their way into urban (i.e., a city or town with >50,000 people; Knuth et al., 2001) environments. Fragmented urban areas benefit some species while negatively impacting others (Gehrt, 2005). Because some wildlife in urban areas (e.g., highly adaptable species like coyotes; Young, 1951; Baker and Timm, 1998; Decker et al., 2001) create conflicts with humans, managers should understand use of urban environments by predators (Atwood et al., 2004; Way et al., 2004). While studies have concentrated on smaller mammals, few studies have examined the ecology of larger carnivores (e.g., cougars, American black bears, coyotes) in urban environments (Torres et al., 1996; Grinder and

Krausman, 2001; Beckman and Berger, 2003; Lyons, 2005). Several aspects of the ecology of coyotes in urban and suburban areas (i.e., the patchwork of residential, commercial, municipal, and industrial lands and related transportation and utility corridors often adjacent to urban centers; Knuth et al., 2001) have been studied, including diet (Quinn, 1997*a*), use and selection of habitat (Quinn, 1997*b*; Gibeau, 1998; Grinder and Krausman, 2001; Atwood et al., 2004), and movements (McClure et al., 1995; Bounds and Shaw, 1997; Quinn, 1997*b*; Way et al., 2004). Coyotes are common in Tucson, Arizona (Grinder and Krausman, 2001). We had the opportunity to study coyotes entirely within central Tucson and, due to new technology (i.e., satellite radiocollars), were able to collect larger datasets than previous studies (McClure et al., 1995; Bounds and Shaw, 1997; Grinder and Krausman, 2001).

Coyotes have been observed in the Colonia Solona and El Encanto neighborhoods of central Tucson since the 1980s. In the early 1990s, complaints about coyotes in these neighborhoods increased, prompting a public survey (G. Frederick, in litt.) and a general study of urban coyotes (Grinder and Krausman, 2001). Complaints about coyotes continued into the 2000s and, in 2005, we initiated a study of coyotes in these neighborhoods.

We studied coyotes in central Tucson during November 2005–November 2006 to assess use of habitat by radiocollared coyotes. We determined size of home range, use of habitat based on land-use categories, movements, and we described a den of an urban coyote. We also were interested in determining if some of these characteristics were similar to those of coyotes that only incorporated parts of urban areas into their home ranges. These data will allow wildlife managers to better understand coyotes in urban areas; thus, informed decisions can be made to reduce human-coyote conflicts.

MATERIALS AND METHODS—*Study Area*—Tucson, Pima Co., Arizona, is in the Santa Cruz River Valley (Sellers and Hill, 1974). Tucson encompasses 587 $km^2$ and has a population of 543,587 (Department of Urban Planning and Design, http://www.tucsonaz.gov/planning/data/tucsonupdate/tudocs/population.html). Average annual (1971–2000) temperature is 20.4°C with average annual rainfall of 32.3 cm (National Oceanic and Atmospheric Administration, http://www.whr.noaa.gov/twc/climate/tuc.php). Tucson has a matrix of stream channels (i.e., washes) throughout the city that are dry most of the year. Washes provide a natural corridor for wildlife with native vegetation including velvet mesquite (*Prosopis velutina*), white-thorn acacia (*Acacia constricta*), catclaw acacia (*A. greggii*), prickly pear cactus (*Opuntia*), and paloverde (*Parkinsonia*).

Our study area included the Colonia Solona and El Encanto neighborhoods and Randolph Golf Course in central Tucson. Both neighborhoods have 2–7 residences/ha. Residences in Colonia Solona are on 0.45-ha lots; lots in El Encanto are 0.16–0.24 ha. Home lots in both neighborhoods have native vegetation, and many contain citrus trees, fruit-bearing palms, and oleanders. Arroyo Chico traverses the southern end of Colonia Solona. Randolph Golf Course is adjacent to Colonia Solona and separated from the neighborhood by a two-lane road, bicycle and walking path, and a 2.5-m-high, chain-link fence. A city park (i.e., Reid Park) is adjacent to Colonia Solona. Randolph Golf Course and Reid Park provide open space and water sources for coyotes.

*Trapping and Telemetry*—We used padded leg-hold traps (No. 3 Victor Soft Catch Coilspring; Animal Trap Co., Lititz, Pennsylvania) to capture coyotes during 4–18 November 2005. Another week of trapping was initiated in February 2006. We covered traps during the day to minimize catching non-target species. We restrained trapped coyotes with a noose pole and muzzle and used cable ties to hobble legs. We recorded sex, mass, general health, and estimated age (<12 months, 1–2 years, >2 years) by tooth wear (Gier, 1968). We fitted coyotes with radiocollars (Global Positioning System–GPS Store-On-Board Model TGW-3402; Telonics, Mesa, Arizona) and released them at the capture site. Radiocollars acquired GPS positions at 0000, 0400, 1200, and 2000 h each day. Radiocollars were equipped with a release mechanism activated on 30 November 2006. We retrieved collars on this date or earlier upon death of the animal. To determine evening, night, and morning movements, we obtained locations of coyotes from the Very High Frequency (VHF) component on radiocollars. The VHF component ran on a 16-h-on:8-h-off cycle beginning at 1800 h MST. We divided the VHF cycle into 4-h sessions starting at 1800, 2200, 0200, and 0600 h and tracked each coyote during every session once/month. We attempted to locate coyotes during a 4-h session at 30-min intervals or less (Gese et al., 1990). We radiolocated animals and attempted to visually locate the animal whenever possible. We recorded locations with a handheld GPS unit or used Google Earth© software (Google Earth version 3.0, Google, Inc.) to obtain a location when a location was known but gathering coordinates would require the researcher to trespass onto private property. We entered triangulation bearings into Location of a Signal (Ecological Software Solutions, Sacramento, California) software to estimate telemetry locations. We used VHF locations to calculate evening, night, and morning rates of movement by calculating average distance moved (m/h) in each 1-h time block during 1800-1000 h. We blocked data seasonally as suggested by Laundré and Keller (1984) and defined four seasons (McClure, 1993): breeding (January–February), gestation (March–April), pup rearing (May–August), and dispersal (September–December). We omitted 1 month of intensive tracking

TABLE 1—Land-use categories, description of categories, percentage of the study area in each category, and percentage of locations of coyotes (*Canis latrans*; $n = 6{,}013$) in each category in Tucson, Pima Co., Arizona, November 2005–November 2006. Whether land-use categories were avoided or selected is indicated for each category ($P < 0.001$).

| Land-use category | Description | Percentage of study area | Percentage of locations |
|---|---|---|---|
| High-density residential (HDR) | Areas with >7 residences/ha, including apartment complexes, townhouses, and condominiums | 40 | 18 Avoided |
| Commercial | Commercial, industrial, and public buildings; resorts, offices, airport | 21 | 9 Avoided |
| Military | All land associated with Davis-Monthan Air Force Base | 11 | 1 Avoided |
| Vacant | Graded vacant land with human disturbances and railway yards | 6 | 8 Selected |
| Road | ≥4-lane roads | 5 | 1 Avoided |
| Park | County, regional, and neighborhood parks; zoos, cemeteries, schools | 4 | 3 |
| Natural | State and federal parks; undisturbed open areas, cropland | 4 | 2 Avoided |
| Medium-density residential (MDR) | Areas with 2–7 residences/ha | 3 | 20 Selected |
| Wash or riparian | Washes and rivers | 3 | 15 Selected |
| Low-density residential (LDR) | Areas with ≤1 residence/ha | 2 | 8 Selected |
| Golf course (GC) | Golf courses and clubhouses | 1 | 15 Selected |

data for an injured female after she was hit by a vehicle; thus, localizing her movements to a 200-m section of wash during the 16 h she was tracked.

*Home Range*—We used Home Range Tools (Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario, Canada) to determine size of home range of each animal with the minimum-convex-polygon method (Mohr, 1947) and the fixed-kernel method (Worton, 1989). We used 95% and 50% of GPS locations for the fixed-kernel method and 95% of GPS locations for the minimum-convex-polygon method to estimate size of home range for each animal. One male shifted his home range during the study. Because we were able to identify an exact date (10 August 2006) of shift, we calculated two estimates of size of home range for him (Riley et al., 2003). Because we calculated size of nine individual home ranges we refer to nine coyotes when referencing home-range polygons. We calculated size of home ranges by season and separately using the fixed-kernel method and we used GPS locations during 1200, 2000, 0000, and 0400 h to identify spatial differences among times. We used descriptive statistics to describe differences in size of home range (calculated using the 95% fixed-kernel method) among seasons due to lack of data (i.e., three coyotes were collared during a single season). We used *t*-tests to determine differences between ages (<2 years old was a subadult and >2 years old was an adult) and repeated-measures analysis of variance (ANOVA; Ramsey and Schafer, 2002) to evaluate differences between size of home range in day (1200 h) and night (0000 and 0400 h).

*Use of Habitats*—We used the Wildlife Habitat Index, an existing land-use coverage created for Tucson in 1995 (W. W. Shaw et al., in litt.), as a base to designate land-use classification of the study area. We updated the Wildlife Habitat Index in ArcGIS 9.2 (Environmental Systems Research Institute, Redlands, California) by consulting land-classification data for Pima County (Pima County Department of Transportation, http://www.dot.co.pima.az.us/gis/pclayers/). We reclassified land-use categories from the Wildlife Habitat Index into 11 categories (Table 1). We overlaid locations of coyotes onto the updated land-use coverage and assigned each location to one of the 11 categories. We used a 99.5% minimum-convex-polygon method (Mohr, 1947) of all GPS locations to delineate the study area. We used a $\chi^2$ goodness-of-fit test (Thomas and Taylor, 1990) to compare makeup of the entire study area to all locations of coyotes collectively. We used polygons derived from the 95% and 50% fixed-kernel methods to estimate size of home range for each individual to determine land-use types available within each home range compared to actual locations within each home range with a $\chi^2$ goodness-of-fit test (Thomas and Taylor, 1990) and Bonferroni confidence intervals (Byers et al., 1984). We also used a $\chi^2$ goodness-of-fit test and Bonferroni confidence intervals to compare size of home range determined by 95% and 50% fixed-kernel methods for each individual to habitat available in the study area. We then compared locations for each individual within each of the four home ranges calculated using the minimum-convex-polygon method by time period to that available in the overall size of home range estimated using the 95% minimum-convex-polygon method for individuals.

We used ArcMap to test for associations between locations of coyotes and washes because we suspected washes were important travel lanes for urban coyotes. We identified all locations within <100 m of a wash by performing a query in ArcMap. We created a 100-m buffer around all washes in the study area to calculate the area that was a wash or within 100 m of a wash. We then performed a $\chi^2$ test to see if more locations occurred more often within 100 m of a wash than would be expected. We used the Create Random Points tool in ArcMap to generate 7,540 (6,013 GPS locations + 1,527 VHF locations) random points within the study area and calculated the percentage of random points located in or within 100 m of a wash. We then compared these to the actual percentage of locations in or within 100 m of a wash.

*Evening to Morning Activity*—We calculated distance between adjacent locations in each VHF tracking session and summed values to estimate distance moved. We used elapsed time between consecutive locations to determine rate of movement (m/h). We pooled tracking sessions for each individual and determined average rates of movement in each land-use category for each tracking session. We used autocorrelated data (Swihart and Slade, 1985) to minimize an underestimation of movements (Reynolds and Laundré, 1990). We used repeated-measures ANOVA (Ramsey and Schafer, 2002) to test for differences in distances traveled among tracking sessions and seasons and differences in rates of movement among tracking sessions. We used data from six coyotes when performing repeated-measures ANOVA. We calculated average distance moved (m) in a diel period by summing distances moved between the four daily GPS locations for each animal and then taking an average for each animal by season. We only calculated a daily distance moved if all four daily locations were present. We used repeated-measures ANOVA for five coyotes to test for differences in distances moved daily by season and age.

*Urban Den*—We located the pack den in Colonia Solona by observing radiocollared males during tracking sessions and confirming presence of pups. Once location of the den was observed from a road in Colonia Solona, we conducted weekly counts of pups and observed behavior near the den during tracking sessions. After the den was abandoned, we measured depth, width, length, aspect, and described vegetation around the den.

RESULTS—*Trapping and Telemetry*—We trapped six of eight coyotes observed in Colonia Solona (four male, two female) during November 2005. We captured two males in February 2006; we trapped one in a leg-hold trap and darted the other with 180 mg of Telazol. Four coyotes were <12 months of age (two male, two female); the remaining were >2 years old. All coyotes appeared to be in good physical condition with no apparent external parasites. Weights ranged from 9.5 (juvenile female) to 13.6 kg (adult male, overall mean = 11.8 ± 0.5 *SE*). We set traps on private property in El Encanto, but after capturing a domestic cat that resulted in negative responses within the neighborhood, we abandoned trapping efforts there. Six mortalities occurred during the study; three coyotes were killed by vehicles, one drowned after becoming trapped in a water-control structure within a golf-course pond, and two died of unknown causes (one was found emaciated in a golf-course pond with an injured paw and the other was within Arroyo Chico in Colonia Solona).

We downloaded 6,013 GPS locations from radiocollars and we collected 1,527 VHF locations of eight coyotes during 11 November 2005–30 November 2006. While tracking, we were able to visually locate target animals or maneuver around the animal on roads so we are confident that VHF locations were assigned to the correct land-use category. We regularly located all coyotes within the city and considered seven to be residents (Atkinson and Shackleton, 1991). The remaining coyote was a lone female, likely a disperser from Colonia Solona. Based on locations, we considered six of eight coyotes to be members of the pack in Colonia Solona. One collared female left Colonia Solona immediately after capture, whereas the other remained in Colonia Solona for ca. 1 week and left the area, returning occasionally. Both females were <1 year old when captured. An adult male captured in February 2006 was associated with the pack in Colonia Solona until 10 August 2006 when he joined another pack ca. 6.5 km away. GPS locations through November 2006 never recorded him returning to Colonia Solona.

*Estimates of Size of Home Range*—Average size of home range of residents as determined using the 95% minimum-convex-polygon method was 22.9 ± 4.2 *SE* $km^2$ (range = 6.8–40.1 $km^2$). Average size of home range of residents using the 95% fixed-kernel method was 26.8 ± 5.1 *SE* $km^2$ (range = 7–46.0 $km^2$; Table 2). The lone female had the largest home range; 62.5 $km^2$ based on the minimum-convex-polygon method and 66.0 $km^2$ using the fixed-kernel method. The male that shifted his home range decreased size of his home range by 30.8 $km^2$ after the shift (15.5 $km^2$ after and 46.0 $km^2$ before). More locations ($n$ = 129) were used in calculating size of home range prior

Table 2—Estimates of size of home range ($km^2$) using the 50% and 95% fixed-kernel methods, and number of locations for radiocollared coyotes (*Canis latrans*) in Tucson, Pima Co., Arizona, November 2005–November 2006. Resident coyotes include all those except 751.

| Coyote | 50% | 95% | Locations |
|---|---|---|---|
| 751 | 5.3 | 67.5 | 1,107 |
| 770 | 1.8 | 30.3 | 980 |
| 789 | 2.2 | 20.8 | 669 |
| 830 | 4.6 | 45.2 | 1,025 |
| 851 | 3.7 | 34.2 | 932 |
| 870—before shift | 7.9 | 46.0 | 504 |
| 870—after shift | 2.6 | 15.5 | 394 |
| 910 | 1.2 | 7.1 | 209 |
| 951 | 1.8 | 1.8 | 208 |
| Mean resident | | 26.8 ± 5.1 | |

to the shift (563 versus 434 locations). Size of home range did not differ between age groups (subadults <2 years old versus adults >2 years old; $t = 0.18$, $df = 8$, $P = 0.864$).

We estimated size of home ranges by season based on 867 locations during the breeding season, 1,293 locations during the gestation season, 1,860 locations during the pup-rearing season, and 1,845 locations during the dispersal season. On average, size of home range during the dispersal season was 15.2 $km^2$ smaller than the other seasons (Fig. 1). There was a difference between size of home ranges in day and night when the size of home range at 0000 h was compared to that for 1200 h ($F_{1,8} = 6.19$, $P = 0.038$) and when 0400 h was compared to 1200 h ($F_{1,8} = 16.54$, $P = 0.003$). Average estimates of size of home range were largest at 0400 h (mean = 29.2 ± 5.2 *SE* $km^2$) and smallest at 2000 h (mean = 8.8 ± 2.8 *SE* $km^2$).

*Use of Habitats*—The study area encompassed 22,344 ha (223.4 $km^2$) of which 40% was high-density residential areas (Table 1). Combined GPS locations from all coyotes were comprised mostly of medium-density and high-density residential areas (Table 1) and were out of proportion to habitats available in the study area ($\chi^2 = 23{,}568$, $df = 11$, $P < 0.001$); coyotes selected medium-density residential areas, washes, and golf courses, but avoided high-density residential areas, natural areas, and commercial categories (Table 1).

Based on the 95% fixed-kernel method, only one coyote had its use of habitat out of proportion to that available in the study area, while six of nine had home ranges, as calculated by the 50% fixed-kernel method, that were out of proportion. However, all coyotes had habitats they used out of proportion to available habitat when compared to the makeup of their individual home ranges as calculated using the 95% and 50% fixed-kernel method ($P < 0.001$). The largest percentage of habitats in the home range of every coyote (based on the 95% minimum-convex-polygon method) was high-density residential areas (≥36%). All coyotes used ≥4 land-use categories out of proportion to availability of habitats when locations were compared to habitats available in their respective home ranges (95% minimum-convex-polygon method; $P < 0.001$). Based on Bonferroni confidence intervals (Byers et al., 1984), all coyotes avoided high-density residential areas, and most avoided commercial areas and roads. All but one coyote selected washes and at least six of nine coyotes selected medium-density residential areas, low-density residential areas, or golf courses. One coyote selected commercial areas. All animals in Colonia Solona had >30% of locations within the medium-density residential, wash, or golf-course categories. Within core areas (determined by 50% fixed-kernel method), eight of nine animals and six of nine animals had less ($P < 0.001$) locations in high-density residential areas and parks, respectively, than expected within the core area. Seven of nine used washes more than expected ($P < 0.001$).

Use of habitat by coyotes varied during the four tracking sessions (Fig. 2). When locations for each individual during each of the four time periods were compared to types of habitat

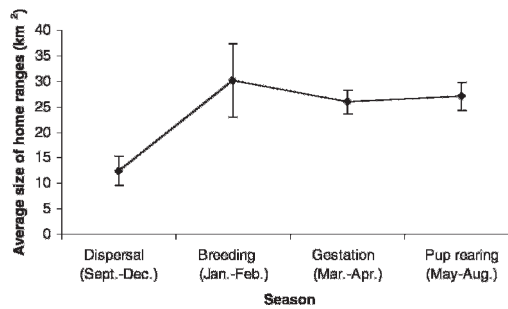


Fig. 1—Average size of home range of coyotes (*Canis latrans*) by season as estimated using the 95% kernel method. Radiocollared coyotes were studied in Tucson, Pima Co., Arizona, November 2005–November 2006.

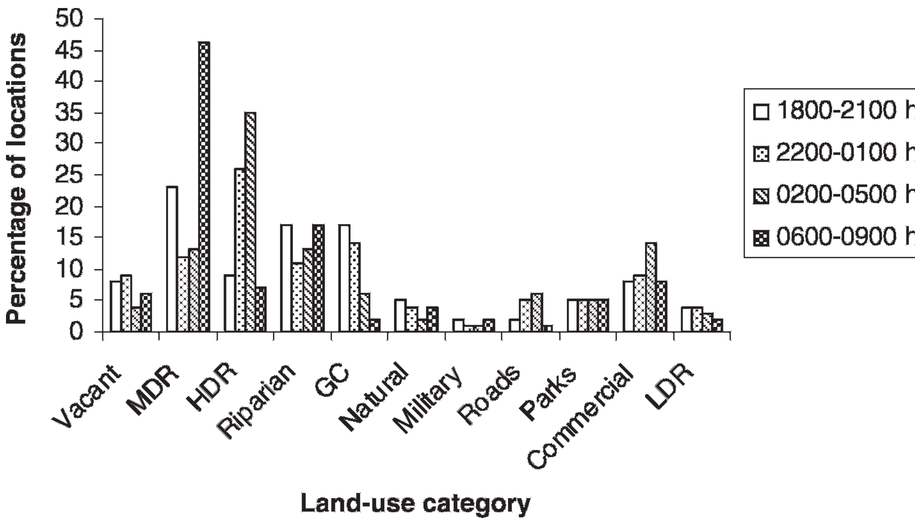


FIG. 2—Percentage of locations of urban coyotes (*Canis latrans*) within land-use categories during four tracking sessions (1800–1000 h) in Tucson, Pima Co., Arizona, November 2005–November 2006; land-use categories are described in Table 1.

available within the home range of the animal (determined by the 95% minimum-convex-polygon method), most coyotes selected golf courses (five of nine), washes (five of nine), and medium-density residential areas (six of nine), and avoided commercial (seven of nine) areas at midnight ($P < 0.001$). Most (seven of nine) coyotes avoided commercial areas, whereas most (six of nine) selected medium-density residential areas at 0400 h ($P < 0.001$). At 1200 h, most coyotes avoided commercial areas (seven of nine), parks (seven of nine), and roads (seven of nine), while most selected medium-density residential areas (seven of nine) and washes (seven of nine; $P < 0.001$). At 2000 h, golf courses, medium-density residential areas, and washes were selected and roads and commercial areas were avoided ($P < 0.001$). One coyote selected commercial areas while one selected vacant areas. During the four time periods, medium-density residential areas and washes were selected by at least six of nine coyotes. Despite high-density residential areas being heavily used at 0000 and 0400 h, high-density residential areas were avoided by all coyotes during each of the time frames ($P < 0.001$). Forty-one percent of actual locations and 16.4% of random locations were either in or within 100 m of a wash. Actual locations were in or within 100 m of a wash more often than expected ($\chi^2 = 545.0$, $df = 1$, $P < 0.001$). Radiocollars collected an average of 480 fewer locations at 1200 h than at the other scheduled retrieval times.

*Evening to Morning Activity*—Due to the high density of roads within the city, we often were able to visually locate coyotes with the aid of telemetry. Coyotes were less often seen while in medium-density residential areas, low-density residential areas, or golf courses at night due to lack of lighting, but were observed easily while they were traveling through high-density residential areas, commercial areas, and across roads. When coyotes were traveling through washes, the matrix of roads allowed us to see them as they traveled.

The greatest rates of movement occurred during 0000-0400 h, with peaks in activity during 0000–0200 h. There was a difference in rate of movement among seasons ($F_{3,5} = 38.3$, $P = 0.007$) and tracking sessions ($F_{3,16} = 26.3$, $P < 0.001$). Rates of movement were greatest during the 0200–0600-h tracking session (mean = 1,509.7 m/h ± 64.1) and least during the 1800–2200-h session (mean = 526.6 m/h ± 37.3). Rates of movement varied among land-use categories (Table 3). Mean rates, across all tracking sessions, were greatest in high-density residential areas and on military land and least in natural areas (Table 3). Rates of movement were lower within land-use categories that coyotes used most during the day and night; i.e.,

TABLE 3—Mean rate of movement (m/h) within land-use categories and tracking sessions for radiocollared coyotes (*Canis latrans*) in Tucson, Pima Co., Arizona, November 2005–November 2006. Land-use categories are described in Table 1.

| Land use | 1800–2200 h | 2200–0200 h | 0200–0600 h | 0600–1000 h | Mean | *SE* |
|---|---|---|---|---|---|---|
| HDR | 532.0 | 1,297.2 | 1,258.9 | 914.6 | 1,099.4 | 114.4 |
| MDR | 336.6 | 725.6 | 764.7 | 370.1 | 460.1 | 25.3 |
| LDR | 331.8 | 456.8 | 416.5 | 463.4 | 447.4 | 71.7 |
| Wash | 309.3 | 665.6 | 812.2 | 235.7 | 519.8 | 53.3 |
| GC | 531.4 | 550.9 | 887.7 | 796.4 | 634.4 | 34.9 |
| Commercial | 337.7 | 825.5 | 948.4 | 256.7 | 787.1 | 119.2 |
| Vacant | 203.4 | 668.8 | 578.6 | 515.4 | 649.6 | 107.8 |
| Natural | 294.0 | 484.2 | 475.9 | 449.5 | 316.9 | 73.9 |
| Park | 490.9 | 1,377.3 | 1,622.7 | 458.6 | 762.0 | 108.2 |
| Military | 1,639.9 | 888.9 | 507.9 | 803.7 | 1,018.7 | 172.3 |
| Roads | 408.7 | 709.2 | 1,024.0 | 512.6 | 780.7 | 77.1 |

medium-density residential areas and washes, and high in areas that coyotes used most during the night (high-density residential and commercial areas; Table 3). Golf courses were used most often during 1900-2200 h; movement through golf courses was similar to rates of movement in washes. Rate of movement was highest during the breeding season (mean = 1,033.1 m/h ± 66.0) and least during the dispersal season (mean = 869.9 m/h ± 53.3). Average distance moved was greatest during the 2200–0200-h and 0200–0600-h tracking sessions (5,609 ± 316.3 m and 5,494 ± 503.3 m, respectively) and least during the 1800–2200-h session (1,696 ± 142.3 m). Overall, coyotes moved an average of 5,556 m in a 24-h period when distances moved were summed between the four daily locations. Daily movements did not differ among seasons ($F_{3,2} = 0.808$, $P = 0.595$) or between ages ($F_{3,1} = 0.434$, $P = 0.774$).

Separating GPS locations by time indicated that different land-use categories were important at different times of the day. When human activity was high and coyote activity was low in midday, coyotes were located mostly in medium-density residential areas and washes. These areas had low human activity and provided cover. Once evening approached and human activity decreased, coyotes used the golf course, but also were located frequently in medium-density residential areas and washes. As the night progressed, activity increased and coyotes moved through high-density residential and commercial areas, likely foraging for domestic cats and other prey. As dawn approached, movement slowed as they most often returned to familiar day-resting spots in washes and medium-density residential areas.

Coyotes were observed eating palm-tree dates, rodents, rabbits, and cats in medium-density residential areas. They only were observed eating cats and dates in high-density residential areas.

*Urban Den*—The radiocollared female did not have pups (the other radiocollared female was killed before breeding season). However, we were able to locate the den in Colonia Solona, an uncollared female and pups, by observing radiocollared males. We observed radiocollared males carrying prey items to the den and spending time at the den. We observed six pups on 29 April 2006 when they were 2.5 weeks old. At ca. 4 weeks, the den was disturbed by humans, and adult coyotes moved the pups to a culvert. The culvert was along a street that provided access to Reid Park and was directly across from a bicycle and walking path, making the pups highly visible to humans. We observed a human approach and photograph the pups. At 9 weeks, pups were moved to another yard in Colonia Solona. We observed eight pups at 4 weeks and five pups at 9 weeks. Three pups were observed at 21 weeks and at the end of the study (November 2006), two pups were regularly observed with the pack in Colonia Solona.

The den was located within a utility easement between two rows of houses. The yard of the house to the south was enclosed with a 1.5-m wall. The yard to the north, the primary travel route, was not fenced. Vegetation surrounding the den was desert scrub, dominated by velvet mesquite, prickly pear cactus, and desert willow (*Chilopsis linearis*). There was no cover over the den, but vegetation increased ca. 15 m to the northeast. The den was linear (0.57-m deep, 5.2-m long, and 0.23-m wide) and the entrance had an aspect of 239°. The den was adjacent to a buried natural gas line that the coyotes had excavated, exposing the gas line. The soil was sandy, and digging was likely made easy because the soil had been disturbed previously for installation of the gas line.

Discussion—*Home Range*—Urban coyotes often have smaller home ranges than their rural counterparts, possibly due to availability of food in urban areas (Shargo, 1988; Bounds and Shaw, 1997; Grinder and Krausman, 2001; Atwood et al., 2004); however, reports of size of home range are varied throughout the literature. For example, Riley et al. (2003) reported that size of home ranges of coyotes was correlated positively with urban association, suggesting urban areas were not as suitable as natural areas. Our estimates of size of home range were larger than in other studies of urban coyotes. Average size of home range for resident coyotes in Tucson was reported previously as 12.6 $km^2$ (Grinder and Krausman, 2001), 1.1 $km^2$ in Los Angles (Shargo, 1988), 8.0 $km^2$ in Chicago (Gehrt, 2006), and 4.5 $km^2$ in southern California (Riley et al., 2003). Because most of our study animals were associated with a single pack, coyotes likely had to range further to find prey items because of many animals (about six) located in the same neighborhood. Coyotes were observed eating rodents, rabbits, and dates within Colonia Solona and El Encanto. They also were observed capturing and consuming 18 domestic cats (Grubbs and Krausman, in press); only two cats were consumed within Colonia Solona or El Encanto. The remaining 16 cats were killed in high-density residential neighborhoods. This may suggest coyotes need to venture away from Colonia Solona for hunting. Larger estimates of size of home range may also be an artifact of technology because we used GPS locations to calculate size of home range, while other urban studies used VHF locations. Ballard et al. (1998) documented that size of territories of the gray wolf (*Canis lupus*) were larger when calculated with GPS collar data than with VHF data. The GPS collars allowed locations to be recorded that likely would not have been recorded if only VHF was available, thus providing a broader picture of areas that our study animals were using.

Unlike the previous study in Tucson (Grinder and Krausman, 2001), we detected seasonal and time-frame differences in size of home range. Size of home range was smallest in the dispersal season, while this season had larger home ranges in other studies (Springer, 1982; Holzman et al., 1992). Because we began trapping during the dispersal season, no study animal was radio-collared during an entire dispersal season. This likely affected estimates of size of home range. We had the largest estimates of size of home range in the breeding season, possibly because coyotes were searching for a mate. As in our study, other researchers have reported large amounts of individual variation in size of home range (Shargo, 1988; Grinder and Krausman, 2001). There is considerable variation among studies relating to size of home range among sexes, ages, and seasons (Laundré and Keller, 1984), likely due to different areas, availability of resources, and techniques. We detected no difference between ages, unlike other studies (Berg and Chesness, 1978; Springer, 1982; Holzman et al., 1992), but two of the four subadults were radiocollared for only ca. 2 months. This might have contributed to under representation of young animals. Also, one surviving subadult was the lone female with the largest home range, thus increasing the estimate of size of home range for subadults.

*Use of Habitats*—Our study area differed from the previous study in Tucson (Grinder and Krausman, 2001) because our study area was centered in the city. The previous study area was 65% natural and 12% residential habitats, compared to the present study, where natural areas made up 6% (4% natural areas plus 2% low-density residential areas, which was included as natural areas in the previous study) and 42% was residential areas.

With one exception, coyotes in our study had random (i.e., use of habitats was not out of proportion to availability) amounts of habitats within their home ranges as estimated by the 95% minimum-convex-polygon method, but locations within home ranges were nonrandom, unlike other studies (Quinn, 1997*b*; Gibeau, 1998; Grinder and Krausman, 2001). Random composition of habitats within home ranges suggests that coyotes did not perceive availability of habitat at a larger scale and were not selecting land-use categories. However, six of nine home ranges had core areas (i.e., estimates of home ranges based on 50% fixed-kernel method) composed of nonrandom land-use categories and selected categories within their core-activity areas. Nonrandom locations within all home ranges indicated that coyotes were selecting for land-use categories within their home range as estimated by the 95% and 50% fixed-kernel method. While each coyote had a large portion (≥36%) of high-density residential areas within its home range, this category accounted for a high proportion of locations, but was still avoided by all coyotes. A possible explanation is that coyotes used this category for travel and hunting (Way et al., 2004) during the night. Therefore, they used high-density residential areas but did not spend large quantities of time in these neighborhoods. Also, the dense matrix of roads within high-density residential areas allows coyotes to move quickly through; similar to travel corridors (e.g., washes). Based on proportion, coyotes mostly selected washes, medium-density and low-density residential areas, and avoided high-density residential areas. Washes and medium-density residential areas offered an abundance of shade and cover, which was likely important during times of high human activity; 41% of all locations were within 100 m of a wash. Additionally, golf courses provided open space and water sources with limited human activity from dusk until dawn. Presence of washes throughout Tucson, and especially in dense residential areas, is likely a reason coyotes persist throughout the city.

Radiocollars collected fewer noon locations than other scheduled retrieval times likely because coyotes were resting under dense cover at midday. When in dense cover, the radiocollar does not always acquire sufficient satellites to obtain a location (D'Eon et al., 2002).

*Evening to Morning Activity*—As in other studies where anthropogenic effects are a factor, we detected increased nocturnal activity (Grinder and Krausman, 2001; McClennen et al., 2001; Way et al., 2004), rather than crepuscular behavior generally seen in rural coyotes (Gipson and Sealander, 1972; Andelt and Gipson, 1979). Nocturnal behavior also has been observed in bobcats (George and Crooks, 2006), red foxes (Adkins and Stott, 1988; Saunders et al., 1997), gray foxes (Harrison, 1997), and American black bears (Reimchen, 1998; Lyons, 2005) in urban areas. Coyotes in our study roamed the city during times when traffic was lighter and human activity was low. This is evident in use of golf courses by coyotes. Coyotes rarely were located on golf courses during times that golfers were present, but most use was after dusk. We determined that rates of movement, which were likely associated with activity (Laundré and Keller, 1984), were greatest in high-density residential, military, and commercial areas. Because these areas were most used by coyotes during the night, coyotes were likely using them to hunt and travel (Andelt and Andelt, 1981; Shargo, 1988; Holzman et al., 1992). They frequently were observed moving through high-density residential areas, the land-use category where most occurrences of consumption of domestic cats were observed. Coyotes were observed resting only in high-density residential areas immediately after feeding or while waiting to feed (after a group had made a kill). Washes provided travel corridors for coyotes within the city (Grinder and Krausman, 2001), but large amounts of time spent resting in washes during the first and last tracking sessions contributed to a lower rate of movement than was expected for a travel corridor. Grinder and Krausman (2001) noted the lowest rate of movement was in residential areas. However, their study did not separate level of housing density in residential areas, and the average rate of movement likely was lowered due to medium-density residential areas.

Estimated distance traveled each day was underestimated when using the four daily GPS locations as a means of calculation. This is noted because average distance traveled for the two middle VHF tracking sessions (2200–0200 and 0200–0600 h) were similar (5,609 and 5,494 m, respectively) to what was calculated as the average daily distance moved (5,556 m). Therefore, researchers should not rely on this means of calculation as an accurate representation of daily movement. If researchers are interested in estimating daily travel distance with GPS collars, it is important to program collars to acquire several locations (e.g., 1/h may be sufficient) when activity is highest.

When washes crossed under roads and coyotes traveled through the wash, they frequently exited the wash to cross over the road, even during times of high traffic. Coyotes placed themselves at greater risk to avoid underpasses in contrast to rural coyotes in Canada that used underpasses when convenient (D. Waters, in litt.). A nearly constant flow of traffic causing excessive noise in underpasses may make underpasses less appealing in urban environments or avoidance of underpasses may be a learned behavior. These observations indicate that underpasses are not a way to mitigate killing of coyotes by vehicles in cities.

Coyotes in our study avoided spending time in areas with high human activity. Coyotes and bobcats in Orange County, California, also restricted their activity in areas of high human activity (George and Crooks, 2006). Red foxes and gray foxes (Harrison, 1997) also used areas away from humans during the day. Coyotes in our study were able to reside in areas with high levels of human activity due in part to the substantial cover provided by washes, and to a lesser extent, medium-density residential areas; these results are similar to those reported by Atwood (2002).

*Urban Den*—Many coyote dens are located in sandy loam soil, most likely for ease of digging (Althoff, 1980; Hallett et al., 1985; Harrison and Gilbert, 1985). The den opening and width (0.23 m) in Colonia Solona was similar to that reported for dens by Hallett et al. (1985; 0.2–0.3 m) and smaller than reported by Althoff (1980; 0.32 m) and Harrison and Gilbert (1985; 0.37). Depth of the den (0.57 m) in Colonia Solona was shallower than dens in Missouri (0.93; Hallett et al., 1985), but deeper than reported by Althoff (1980) for dens in Nebraska (0.18–0.51). The den in Colonia Solona was likely only excavated to the same depth of the original gas line. Aspect of the den in Colonia Solona was southwest, but Hallett et al. (1985) noted that 73% of dens were south facing, whereas Althoff (1980) reported north-facing and east-facing dens as most common.

Coyotes live, hunt, and reproduce within cities, yet little is published describing urban dens, an important part of understanding their ecology (Althoff, 1980). Dens have been reported in culverts under heavily trafficked roads, basements of abandoned houses, and directly behind a drive-in movie screen (Froman, 1961). It is important to document locations of urban dens so managers can predict where den sites will be located. However, from other documented urban dens, almost no place is excluded. Awareness by residents and personnel of utility companies of previous locations of dens can promote increased vigilance and periodic checking of utility easements, especially during denning season to prevent exposed utility lines. The gas company filled in the den we discovered because of the exposed gas line.

*Management Implications*—Our inferences are limited because of small samples, narrow time frame (i.e., 1 year), and high mortality. Inferences also are restricted because we trapped only within a small area and, therefore, radiocollared most members of one pack, providing similar data among animals. However, we were able to gather useful information about this urban pack of coyotes. For example, sex of the pack in Colonia Solona was highly skewed toward males; only one female was a member of the pack throughout most of the study. Males were favored in other studies, particularly where population exploitation was low (Gier, 1968; Hawthorne, 1971; Gese et al., 1989). We also were able to observe natural replacement of coyotes; during August 2006, the pack in Colonia Solona lost three adult males due to death or shift in home range. Two coyotes joined the pack after these losses occurred. We also observed that number of pups decreased from eight to two.

While this study has provided valuable insight into the ecology of coyotes that use the city of Tucson (e.g., available land-use categories are an important determinant in size of home range, coyotes generally avoid humans, and behavior of urban coyotes has shifted from crepuscular to nocturnal) for all activities, there is more to learn. We can surmise that coyotes have done well in this particular area due to available resources and a diversity of land-use types. The pack in Colonia Solona heavily used the medium-density residential areas of Colonia Solona and El Encanto, Arroyo Chico, and Randolph Golf Course with nightly excursions through high-density residential areas. It is unclear whether these nightly excursions were necessary to fulfill food requirements or if coyotes could survive on food resources available solely within Colonia Solona, Arroyo Chico, and Randolph Golf Course. It would be useful to know the land-use habits of other packs that are similar in size to the pack in Colonia Solona. A larger sample with animals from several packs within Tucson would provide a holistic picture of urban coyotes in Tucson and provide information on interactions of packs.

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