Landscape-level habitat use and movement patterns of black bears in northeastern Arizona

LANDSCAPE-LEVEL HABITAT USE AND MOVEMENT PATTERNS OF BLACK BEARS IN NORTHEASTERN ARIZONA

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Abstract—Little is known about black bear (*Ursus americanus*) populations in northeastern Arizona, an area characterized by rugged canyon topography and varied habitat composition. We placed global positioning system collars on four bears in this area to characterize second-order, landscape-level habitat use and examine habitat use and movement patterns of bears across this landscape. Data from four global positioning system collars revealed that bears use areas with higher tree canopy cover and terrain ruggedness, indicating that forest and escape cover are important factors driving black bear habitat use at the landscape level. Movement patterns revealed long, linear mean daily movements that follow the structure of the canyon topography. These long, linear movements also allow bears to take advantage of the mosaic of habitats and food resources available in this unique landscape.

Resumen—Se sabe poco acerca de las poblaciones de osos negros (*Ursus americanus*) en el noreste de Arizona, una zona que se caracteriza por una topografía irregular de cañones y composición variada de hábitat. Pusimos collares GPS en cuatro osos en esta zona para caracterizar el uso de hábitat a nivel de paisaje y de segundo orden, y para examinar el uso de hábitat y patrones de movimiento de los osos en este paisaje. Datos de los cuatro collares revelaron que los osos usan zonas con alta cobertura de dosel y de alta irregularidad de terreno, indicando que la cobertura del bosque y sotobosque son factores importantes que influencian el uso de hábitat de los osos a través del paisaje. Los patrones de movimiento revelaron una larga , linear media de movimientos diarios que se amoldaron a la estructura de la topografía del cañón. Estos movimientos largos, lineares también facilitan a los osos el aprovechamiento del hábitat de mosaico y de recursos alimenticios disponibles en este paisaje único.

Little is known about black bear (*Ursus americanus*) populations in the Navajo Nation in northeastern Arizona. LeCount et al. (in litt.), Mollahan (in litt.), and LeCount and Yarchin (in litt.) conducted habitat use studies of black bears in the central part of the state, where habitat composition is strikingly different; thus results of those studies cannot easily be transferred to the northeastern part of the state. Canyon de Chelly National Monument (CACH), the Chuska Mountains (Chuskas), and the intervening landscape (Fig. 1) provide a mosaic of food resources and forest cover for black bears that follow the highly variable elevation and topographic gradients in a relatively small area. Vegetation cover types include pinyon/juniper (*Pinus edulis/Juniperus osteosperma*) forests, higher-elevation ponderosa pine (*Pinus ponderosa*) forests, and lower-elevation riparian and grassland areas (Rink, 2005). In addition, this region is characterized by uniquely rugged, linear canyon topography that we suspect influences bear movement differently from that in other areas across their range. Our objectives were to characterize landscape-level (second-order) habitat use (Johnson, 1980) by black bears in northeastern Arizona and examine intradiel and seasonal differences in habitat use and movement patterns of bears across this landscape.

CACH spans 340 km^2 in the heart of the Navajo Nation in northeastern Apache County, Arizona (Fig. 1). The canyon system is incised into the northern portion of the Defiance Plateau and the canyons were cut by streams with headwaters in the nearby Chuska Mountains. The Chuska range is relatively small ($\sim$80 $\times$ 15 km) and lies directly on the border between Arizona and New Mexico. Average elevation is 2,740 m, with the highest peak at 2,994 m. The mouth of CACH sits at 1,680 m, with upper slopes reaching 2,320 m. Upstream canyon walls attain heights of 250–350 m, whereas the lower canyon is characterized by a wide (0.2–1.0 km), flat, sandy streambed with relatively low cliff walls (Rink, 2005). Vegetation across this landscape is diverse, ranging from desert scrub/grassland communities, pinyon/juniper,
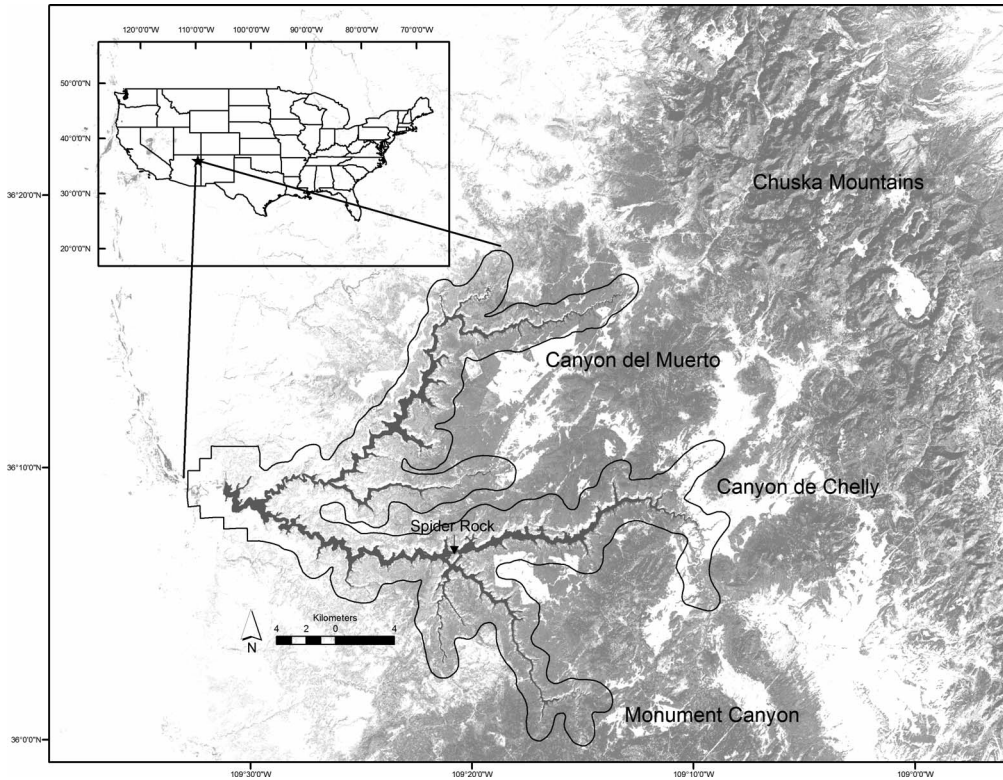
Fig. 1—Map of Canyon de Chelly National Monument (Apache County, Arizona) and surrounding areas where movements of black bears (*Ursus americanus*) were studied. Monument boundary is designated by bold black line. Darker shading indicates higher forest cover.

ponderosa pine, Douglas fir (*Pseudotsuga menziesii*) and aspen (*Populus tremuloides*), and small areas of spruce fir (*Picea engelmannii*) forest as elevations increase (Novak, 2007). Native bear foods are abundant across the landscape and include pinyon pine, Utah juniper, gambel oak (*Quercus gambelii*), Rocky Mountain juniper (*Juniperus scopulorum*), Utah serviceberry (*Amelanchier utahensis*), scrub oak (*Quercus turbinella*), narrowleaf yucca (*Yucca angustissima*), banana yucca (*Y. baccata*), and prickly pear and cholla cacti (*Opuntia* spp.). Riparian areas across this landscape have changed substantially over the past century, shifting from wide-open stream channels with minimal vegetation cover to deeply incised channels choked with nonnative Russian olive (*Elaeagnus angustifolia*) and tamarisk (*Tamarix* spp.; Reynolds and Cooper, 2010). Black bears use the Russian olive as one of their primary food sources (Tredick et al., 2016).

We captured bears in CACH during summer 2008 and 2009 and fit all bears >40 kg with global positioning system (GPS) collars (3300S, Lotek Wireless, Inc., Newmarket, Ontario, Canada) equipped with breakaway cotton spacers (Hellgren et al., 1988). Collars were programmed to record locations every 5 h. Capture and handling procedures followed guidelines set out by the American Society of Mammalogists (Gannon et al., 2007) and were approved by the Animal Care and Use

Committee at Virginia Tech (IACUC protocol #08-056-FIW).

We extracted six landscape-level habitat variables from a geographic information system for use in our habitat models: tree canopy cover (U.S. Geological Survey National Land Cover Database; Homer et al., 2004), elevation (National Elevation Data Set; Gesch et al., 2002), terrain ruggedness (vector ruggedness measure; Sappington et al., 2007), primary roads (Census Tiger/LINE database; U.S. Census Bureau, 2000), and streams and springs (U.S. Geological Survey National Hydrography Data Set; Simley and Carswell, 2009). As most streams in this region are generally dry throughout most of the year (Reynolds and Cooper, 2010), this variable was used as a surrogate for energetically efficient travel and foraging corridors, which we predicted would be used preferentially by bears. We evaluated these variables across the entire landscape, representing second-order habitat selection by bears (Johnson, 1980). We defined the analysis landscape by calculating a 100% minimum convex polygon from all bear locations collected during the study, and used a Design II use-availability sampling design (Thomas and Taylor, 2006). GPS collar locations from all bears represented use, and an equal number of randomly selected points across the landscape represented availability. We extracted values for tree canopy cover, elevation, and vector ruggedness measure at each of the

used and available locations without buffering and we measured distance to nearest road, nearest spring, and nearest fourth-order or higher stream for all used and available points within the geographic information system. We compared a use vector of all habitat variables (mean $\pm$ 95% confidence interval) with the landscape-level availability vector to characterize differences in used and available locations. We separated daytime (0700–1859h) and nighttime (1900–0659h) locations to evaluate intradiel differences in habitat parameters, and evaluated seasonal differences (spring = den emergence to 21 June; summer = 21 June–31 August; fall = 1 September to den entry) in habitat parameters used by each bear tracked in multiple seasons. Because of spatial autocorrelation in these data, significance tests were not conducted.

We initially evaluated each predictor variable using simple logistic regression, assessing significance in predicting black bear habitat use with a Wald chi-square statistic. Only significant variables ($p < 0.05$) were considered in further analyses. Since data from GPS telemetry locations tend to be spatially autocorrelated, we used a cluster-correlated form of the Huber–White sandwich estimator to calculate robust standard errors for these estimates (Clark and Stevens, 2008). We also evaluated multicollinearity among predictor variables using Pearson's correlation coefficients to avoid using highly correlated variables ($|r| > 0.7$) in the same models. For the final habitat use analyses, we used generalized linear mixed models, which have been shown to handle the inherent variation in habitat selection among individual animals (i.e., random effects), and can correctly adjust parameter estimates to account for spatial autocorrelation and unbalanced sampling among animals (Gillies et al., 2006; McLoughlin et al., 2010). The dependent variable was binomially distributed as zero (available locations) or one (used locations), and probability of use, $w \times (x)$, was calculated using the logit link. Because maximum-likelihood estimates for generalized linear mixed models are fit using only a restricted pseudolikelihood, we used results from fixed-effects-only models (removing the random effect and thus allowing true likelihood estimation) to select best-fitting models using an information-theoretic approach. All analyses were carried out in SAS 9.2 (SAS Institute, Inc., Cary, North Carolina).

In addition to habitat use models, we also characterized bear movement patterns by calculating mean daily and total distances moved by bears over the entire study, mean hourly step lengths (total distance moved in 1 h), turning angles, and direction of movements to examine how bears were moving across the landscape. We evaluated intradiel differences in these patterns, and also evaluated seasonal differences in movement parameters for each bear tracked in multiple seasons.

We captured four adult bears (one female, three males) and collected 1,071 GPS locations between summer 2008 and fall 2010. Mean ($\pm SE$) number of locations per bear was 268 $\pm$ 15 (range = 24–509 locations). Average interval ($\pm SE$) between locations for all bears was 7.7 $\pm$ 0.196 h. Mean ($\pm SE$) monitoring interval for all bears was 157 $\pm$ 7 days. We tracked two of the male bears for only 11 and 24 days, and one male and one female for 147 and 339 days, respectively.

There were substantial differences in landscape characteristics used by bears compared with the overall composition of the landscape. Relative to availability across the entire landscape, bears used areas with higher tree canopy cover and terrain ruggedness (vector ruggedness measure), farther from streams, closer to roads, and at lower elevations (Fig. 2). During the day, bears used areas with higher tree canopy cover compared with nighttime locations (Fig. 2). SEs overlapped for nighttime and daytime locations for all other variables. The two bears tracked in multiple seasons (one male, one female) used higher canopy cover and higher elevations during spring and fall compared with summer. They also used areas closer to springs and with higher ruggedness in summer. The male bear used areas with substantially lower cover in the summer than the female. The female bear used habitat farther from roads than the male bear in summer and fall, and was substantially farther from streams in summer. She also used more rugged areas in spring compared with summer and fall (Fig. 2).

None of the habitat variables used in regression models were highly correlated with one another (Pearson's $|r| > 0.7$); thus all combinations of variables were evaluated in model runs. Bears showed significant ($P < 0.01$) responses to all habitat variables used in simple logistic regression models. Because of high spatial autocorrelation and unbalanced sampling of locations in the data, however, standard errors or beta estimates are likely to be underestimated. Including random effects and estimating standard errors of beta coefficients using the Huber–White sandwich estimator did increase standard errors and confidence intervals on odds ratios, suggesting that autocorrelation and unbalanced sampling design were correctly adjusted for in subsequent generalized linear mixed models (Table 1).

Parameter estimates and directional relationships were similar for fixed-effects-only models and models incorporating individual bears as a random effect (Table 1). Model selection results based on corrected Akaike information criterion values from fixed-effects models suggested that the best model for predicting landscape-level habitat use by black bears included all six habitat variables (Table 2). This model received 99% support. Adjusted odds ratios of coefficients from the best random-effect model predicted a 4% increase in probability of bear use for every 1% increase in tree canopy cover, a 69% increase in use for every kilometer farther from a stream, and a 22% decrease in use for every kilometer farther from a road. In terms of topography, odds ratios predicted a 1% decrease in
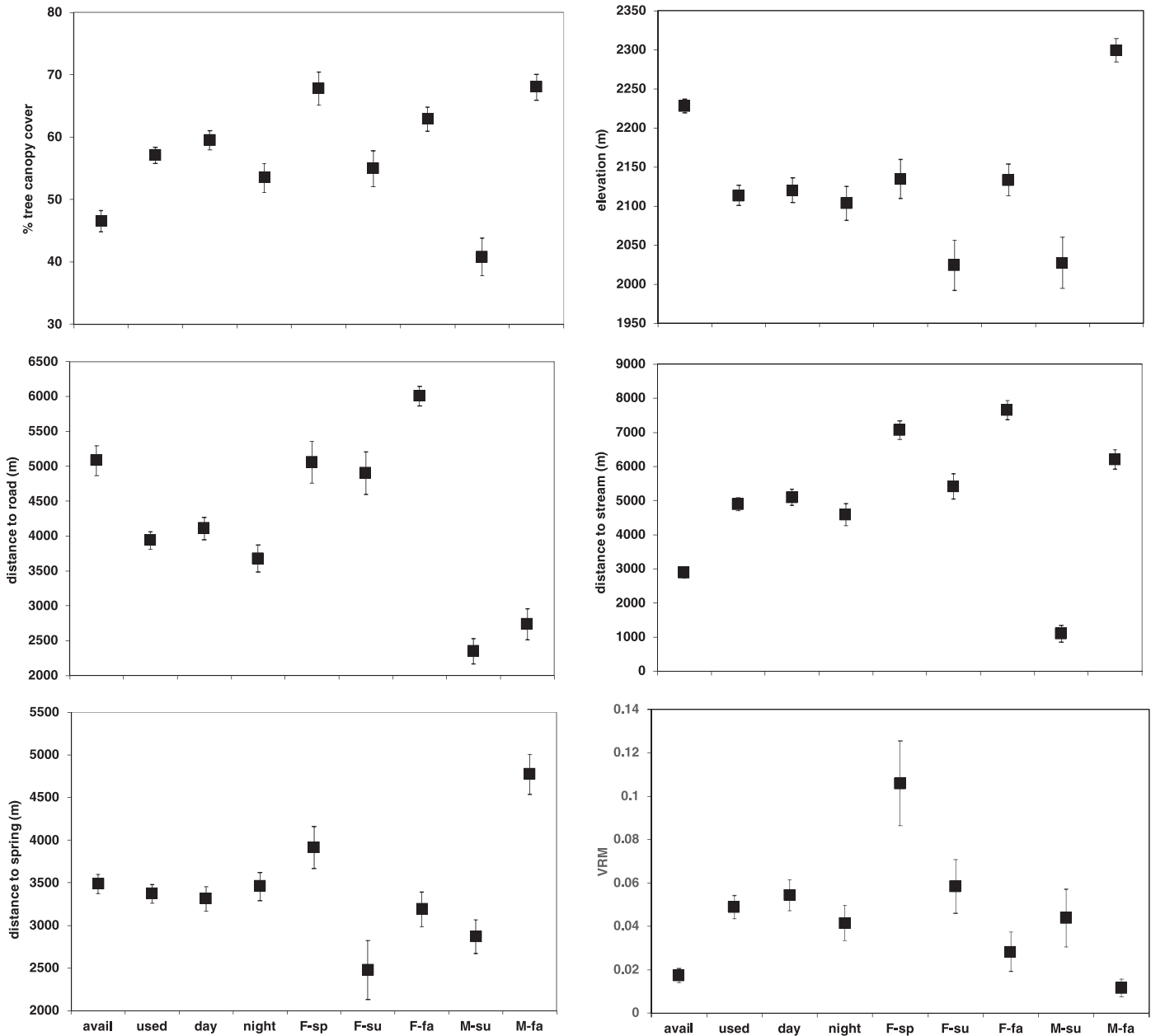
Fig. 2—Comparison of habitat variable distributions (mean ± *SE*) of locations available to bears in Canyon de Chelly National Monument (Apache County, Arizona) and surrounding areas during 2008–2010, and locations used by bears across the entire landscape ($n = 1,071$; all), during the day and night, and during different seasons. F = female, M = male; sp = spring, su = summer, fa = fall. See text for time and season delineations.

probability of use for every meter increase in elevation, and 3% increase in use for every unit increase in ruggedness (note that mean vector ruggedness measures for used and available sites were between 0.01 and 0.05). Distance to nearest spring was not a significant predictor of bear habitat use by itself (Table 1).

Bears exhibited relatively linear movement patterns and long mean daily movements during the study. Mean daily movement rates ranged from 2.3 to 6.1 km (range = 0–26.2 km) and were smallest for the female bear. Daily movements of the female were substantially smaller in the

spring (1.4 [*SE* = 0.18] km/day) compared with summer or fall (2.7 [*SE* = 0.29] and 2.8 [*SE* = 0.29] km/day, respectively). Movements of the male tracked in multiple seasons were higher in the fall (5.4 [*SE* = 0.58] km/day) compared with summer (4.5 [*SE* = 0.50] km/day). Two male bears made extensive movements out of CACH. One moved from upper Canyon del Muerto into the Chuskas (~38 km) in ~60 h, then returned back into CACH below his initial starting point within 1 week. Another male moved south from Monument Canyon to a location near the town of Navajo, New Mexico (~55 km) and returned

TABLE 1.—Parameter coefficients, odds ratios, and 95% confidence intervals for the most highly supported random-effect regression model and from a simple logistic regression model of landscape-level habitat selection of black bears (*Ursus americanus*) in Canyon de Chelly National Monument (Apache County, Arizona) and the surrounding landscape during 2008–2010. Odds ratios > 1.0 indicate a positive relationship to the parameter, and values < 1.0 indicate a negative relationship.

				Odds ratio estimates	
				95% Confidence limit	
Parameter	β	SE	Ratio	Low	High
Random-effect model:					
Canopy cover	0.041	0.008	1.041	1.034	1.050
Elevation	−0.009	0.003	0.990	0.985	0.996
Distance to road	−0.251	0.068	0.778	0.680	0.889
Distance to spring	−0.252	0.165	0.777	0.562	1.074
Distance to stream	0.527	0.253	1.693	1.031	2.781
VRM[a]	0.035	0.016	1.036	1.020	1.051
Simple logistic model:					
Canopy cover	0.041	0.003	1.041	1.039	1.045
Elevation	−0.009	0.000	0.991	0.991	0.992
Distance to road	−0.278	0.024	0.757	0.723	0.793
Distance to spring	−0.190	0.036	0.827	0.770	0.888
Distance to stream	0.418	0.026	1.519	1.445	1.597
VRM	0.030	0.009	1.030	1.022	1.039

[a] Vector-ruggedness measure.

to Monument Canyon over a period of 30 days. Mean hourly step length for all four bears was 187 m (*SE* = 8.06; range = 0–2,106 m). Most (71%) of all hourly step lengths were shorter than 200 m. Mean daytime hourly movements (196 m; *SE* = 10.46; range = 0—1,639 m) were slightly higher than nighttime hourly movements (174 m; *SE* = 12.62; range = 0–2,106 m). Mean turning angle for all four bears was 35° and mean direction of movement was 0°. Daytime turning angles were slightly higher than nighttime turning angles. Mean hourly step length for the male bear was substantially higher in the fall compared with summer (fall = 290 m, *SE* = 21.94; summer = 225 m,

SE = 22.16). No differences were seen in hourly step lengths for the female bear between summer and fall (fall = 134 m, *SE* = 11.31; summer = 132 m, *SE* = 12.42), but mean hourly step length for the female in spring was substantially lower than in fall or summer (spring = 68 m, *SE* = 8.52). No differences in seasonal turning angles or movement directions were found.

Our results illustrate that the four black bears studied select for a suite of habitat characteristics at the landscape scale, which is consistent with the hypothesis of bears being a landscape species and habitat generalist (Harris and Kangas, 1988; Schoen, 1990; Maehr, 1997; Samson

TABLE 2.—Logistic regression results of landscape-level habitat selection models for black bears (*Ursus americanus*) in Canyon de Chelly National Monument (Apache County, Arizona) and the surrounding landscape during 2008–2010. (*k* = no. of parameters, AIC_c = Akaike's information criterion corrected for small sample size, $\Delta AICc$ = change in AIC_c, and w_i = the relative amount of support for the model).

Model	k	AIC_c[a]	ΔAIC_c	w_i
Canopy cover − elevation − distance to road − distance to spring + distance to stream + VRM[b]	6	1,857.37	0	0.990
Canopy cover − elevation − distance to road − distance to spring + distance to stream	5	1,866.63	9.26	0.010
Canopy cover − elevation − distance to road + distance to stream + VRM	5	1,883.47	26.1	< 0.001
Canopy cover − elevation − distance to road + distance to stream	4	1,893.77	36.4	< 0.001
Distance to stream	1	2,729.06	871.69	< 0.001
Elevation	1	2,775.83	918.46	< 0.001
VRM	1	2,868.98	1,011.61	< 0.001
Canopy cover	1	2,883.81	1,026.44	< 0.001
Distance to road	1	2,892.68	1,035.31	< 0.001
Distance to spring	1	2,971.29	1,113.92	< 0.001

[a] AIC_c values are from fixed-effects models. See text for details.
[b] Vector-ruggedness measure.

landscape, from low-elevation scrub/grassland communities, to high-elevation conifer forests, and to pinyon/juniper forests above the canyon rims. Specifically, bears selected areas with higher tree canopy cover and terrain ruggedness, suggesting that forest cover and escape cover are primary factors driving black bear habitat selection at the landscape scale in this region. Although elevation was a significant predictor of black bear habitat use in CACH, the ruggedness measure better captured the variability in topography across the landscape and explained how bears use the unique topography of this landscape.

We also found that bears select areas farther from streams and closer to roads, which was unexpected given results from previous studies. We hypothesized that bears would use stream corridors or drainages as travel corridors and important foraging areas, and although this did seem to be the case at a finer scale (third-order, within-home-range habitat use) in CACH (Tredick et al., 2016), results in this study suggest that bears did not prefer these stream corridors at the landscape scale. Although many previous studies have found that bears avoid roads (Brody and Pelton, 1989; Reynolds-Hogland et al., 2007), roads in this study area are not heavily trafficked and are therefore unlikely to impede bear movements. Furthermore, two of the primary roads defined in the study area run along the rims of the major canyons; thus, although bears might be geographically close to these roads, canyon walls separate these roads from canyon bottom areas used by bears. This likely generated a stronger effect due to roads than actually exists in CACH.

Movement patterns by the four bears in this study also support the hypothesis of the black bear as a landscape species and habitat generalist. Large mean daily movements combined with low average turning angles indicate long, linear movements, suggesting that bears in this study are not limiting use to one area of the landscape, but rather are taking advantage of the mosaic of available habitats and food resources available across the entire area. The linear movement patterns of bears in this landscape are likely driven by the linear nature of the canyons and mountains that define it. Variable elevation gradients and soil profiles generated by the steep and rugged terrain lead to a heterogeneous vegetation structure and composition across the landscape, primarily following the linear contours of CACH and other drainages. Bears subsequently follow this linear structure as they exploit this mosaic of vegetation resources, leading to long, narrow movement patterns that span wide areas of the region. Shorter hourly movements (<200 m) indicate that bears are spending time in each of the various habitat types (i.e., foraging), rather than just quickly moving through. One exception to this pattern, however, seems to be for the male bear that traveled from CACH into the Chuskas. Location data indicated that he moved relatively rapidly through the habitat matrix between these areas, which included the relatively more populated areas of Tsaile, Arizona. This suggests that areas more heavily used by humans are not preferred habitats.

Seasonal differences in movement parameters were consistent with previous studies of black bear habitat use. Both the male and female bears exhibited higher mean daily movement rates in the fall compared with summer or spring, consistent with the onset of hyperphagy to develop adequate fat reserves for winter (Garshelis and Pelton, 1981; Beck, 1991; Costello et al., in litt.). Furthermore, movements of the female bear were substantially restricted in the spring, as evidenced by lower hourly and daily movement rates, and she also selected more rugged areas in the spring. This is consistent with other studies that attribute this limited movement ability to the presence of cubs and different energetic needs during this period (Lindzey and Meslow, 1977; Powell et al., 1997), though we were not able to verify if the female had cubs present.

Results from this landscape-level analysis can be further contrasted with results from fine-scale, within-home-range habitat use of black bears in CACH (Tredick et al., 2016). Namely, it appears that second-order, landscape-level habitat selection is driven by the need for forest and escape cover, whereas third-order, within home-range-level habitat selection is driven by the availability of food. This is consistent with other studies of bear habitat use. For example, Lyons et al. (2003) found that bears in Washington selected for prime food sources at the third order, but were using forest cover more at the second order. Contrastingly, Mollahan et al. (1989) and LeCount and Yarchin (in litt.) concluded that forest cover was more important than food availability at the third order for bears in central Arizona. In this study, topography played a more important role for black bears at the landscape scale. It is important to note that we did not have access to a direct measure of food availability at the landscape scale, and inclusion of such a parameter could have altered model results. Nevertheless, food availability seems to be more diverse and abundant within the boundaries of CACH (Tredick, pers. obser.), yet areas outside of CACH were used readily by bears in this study, suggesting that perhaps forest cover is indeed the driving factor in habitat selection at the landscape scale.

Because of low sample size our results should be interpreted with caution. Although generalized linear mixed models generated more robust results with spatially autocorrelated data and uneven sampling, it is unclear how well these models perform given low sample sizes. Additionally, movement parameters are largely derived from two bears monitored for less than a full year and thus may not be representative of bears across the entire study area. For example, forest cover, food availability, human-use areas, and topography are substantially different in the northern portion of the study area compared with the southern area where most of our study occurred. However,

results provided here offer valid information on black bear habitat use and movement patterns in a unique area that has not been studied previously. Our findings that bears exhibited long, linear movements, selected forest and escape cover, and used a wide variety of habitat features provide managers with new insight into bear behavior and resource requirements, information useful for understanding bear ecology and for more effective bear management in this region.

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