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Assimilated diet patterns of American black bears in the Sierra Nevada and western Great Basin, Nevada, USA

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Abstract: In western Nevada, USA, the American black bear (*Ursus americanus*) coexists with humans and increasing urban sprawl. Hotels, casinos, restaurants, and homeowners dispose large quantities of high-protein, calorie-rich foods, often in unsecured waste containers. We used 173 hair samples from black bears captured in western Nevada from 2003 to 2010 and conducted δ^{13}C and δ^{15}N analysis to examine anthropogenic food use. We developed a set of a priori models to examine the effect of biological (sex, age class, mass category [considering sex and age]), chronological (season, molt phase, and year), and spatial (urban–wildland classification [UW class]) factors potentially affecting use of anthropogenic foods and accompanying stable isotope signatures. Bears in above-average mass categories had enriched ^{13}C and ^{15}N signatures compared with bears of below-average mass. Wildland bears had depleted ^{13}C compared with urban bears and appeared to use human foods less. Postmolt hair samples (representing late-spring–early summer diet) were depleted in both ^{13}C and ^{15}N relative to premolt hairs (late-summer–autumn diet), indicating changes in food availability. Male black bears had enriched ^{15}N compared with females, indicating more meat in their diet. Our results indicated substantial ^{13}C and ^{15}N enrichment of black bear diets in Nevada, which was affected by biological, chronological, and spatial factors. Using mixing models of the 2 isotopes, we found both urban and wildland bears relied on natural and anthropogenic foods, with wildland bears using wild foods more often. There was only 3.8% difference in the median use of human foods between urban and wildland bears, but great variability for individual bears in each location category. Our results affirmed that, to effectively address human–bear conflicts, officials should emphasize exclusion of anthropogenic food attractants on a year-round basis and further try to understand factors affecting individual bear use of garbage.

Key words: American black bear, carbon, diet patterns, Lake Tahoe, Nevada, nitrogen, stable isotopes, urban and wildland bears, *Ursus americanus*

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Viable populations of American black bears (*Ursus americanus;* hereafter, black bear) and grizzly bears (*U. arctos*) were extirpated from the interior mountain ranges of Nevada, USA, by the early1900s, in part as a result of predator removal efforts and landscape-scale habitat changes caused by deforestation in several mountain ranges across the state (Beckmann and Lackey 2008, Lackey et al. 2013). However, remnant populations of black bears occurred in the Sierra Nevada along the Nevada–California border near Lake Tahoe and these populations began to expand (Malaney et al. 2018). It is thought that this expansion was a result of a slow reforestation of Nevada's mountain ranges initiated by the nation's growing dependency on fossil fuels post–World War I, combined with changes in grazing practices and forestry practices, such as wildfire control (Nevada Forests Industries Committee 1963). By the early 1980s, black bear sightings, human–bear

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conflicts, and bear deaths from vehicles remained rare events in Nevada (LeCount 1979, Goodrich and Berger 1994). By the late 1980s, a population of black bears occupied western Nevada (Goodrich 1990) and by the mid-1990s, conflicts between humans and black bears began to rise sharply in the Lake Tahoe Basin and the western portion of the Great Basin Desert (Beckmann 2002; Beckmann and Berger 2003a,b). A 10-fold increase in the annual number of complaints and a 17-fold increase in bear mortalities, due to collisions with vehicles, were reported between the 1990s and early 2000s (Beckmann 2002; Beckmann and Berger 2003a,b). These increasing human–bear conflicts were the impetus for a long-term research and monitoring effort beginning in 1997 to understand black bear ecology and conservation in the region (Beckmann 2002; Beckmann and Berger 2003a,b; Lackey et al. 2013). Current estimates of the population are 500–700 individuals and the population is expanding in the Great Basin, including areas with increased human presence and activity (Lackey et al. 2013).

Black bears in western Nevada are exhibiting demographic and behavioral changes influenced by anthropogenic modification of the environment. These changes include shifts in home range size and location, activity patterns, denning chronology, fecundity, dietary changes, mass, and demography (Beckmann and Berger 2003a,b; Beckmann and Lackey 2008; Lackey et al. 2013; Johnson et al. 2015). Fully understanding the effects of human-modified landscapes on the individual bear and at the population level is important to help managers make management decisions to reduce human–black bear conflicts.

Continued expansion of the black bear population in Nevada may influence conservation and management planning efforts in areas heavily populated by humans. Areas that offer suitable bear habitat, despite anthropogenic modification, may be recolonized by bears in the future and should also be evaluated (Beckmann and Lackey 2008, Lackey et al. 2013). Given that Nevada is one of the fastest growing states in the United States with a human population about to reach 3 million (World Population Review 2016), and is a state in which most of the population resides in urban settings, the rapidly increasing human footprint in Nevada will bring challenges with the continued expansion of the bear population. Here we use hair samples collected from bears in the Sierra Nevada and western Great Basin from 2003 to 2010 and stable carbon and nitrogen isotope analysis to assess differences in biological, chronological, and spatial factors affecting use of anthropogenic foods. Stable isotopes can indicate greater use of human foods because the corn-based diet causes an enrichment of ^{13}C and high meat content increases ^{15}N. Our primary objective was to gain a better understanding of factors associated with bear use of human-derived foods. Such information is important to guide efficient and effective management of human–bear conflicts and to determine what type of data should be collected when a bear is handled as a result of a complaint or conflict.

Study area

The current distribution of black bears in Nevada is restricted to the Carson Range of the Sierra Nevada, Pine Nut Mountains, Pine Grove Hills, Sweetwater Range, Virginia Range, Aurora Hills, and the Wassuk Range in western Nevada (Beckmann and Berger 2003a,b; Lackey 2004). These mountain ranges and associated basins cover an area of approximately 12,000 km^2 and are characterized by steep topography with high granite peaks and deep canyons. Mountain ranges are separated by desert basins that range from 16 to 64 km across (Grayson 1993). These basins are often large expanses of unsuitable habitat (e.g., large areas of sagebrush [*Artemisia* spp.]) that bears do not use as primary habitat (Goodrich 1990, Beckmann and Berger 2003a). Black bears in this region are at the eastern edge of their current range in the Great Basin, with the closest Great Basin population being approximately 750 km to the east in Utah. However, recent evidence suggests the black bear population is expanding back into historical habitat in the central and eastern Great Basin (Lackey et al. 2013). The study area extends from the Carson Range of the Sierra Nevada eastward to the Virginia Range and Pine Nut Mountains, and from Reno south to the Aurora Hills. Many bears were captured in response to conflicts, but these captures occurred primarily at the wildland–urban interface of cities and towns within the study area and included developed areas in the Lake Tahoe Basin: Incline Village, Glenbrook, Cave Rock, Zephyr Cove, and Stateline, and the lower elevation urban centers of Reno, Carson City, Minden, and Gardnerville.

Materials and methods

Sample collection

The Nevada Department of Wildlife (NDOW) collects hair samples from all bears handled through human–bear conflicts, research, and mortalities. We captured bears using culvert traps (Teton Welding, Choteau, Montana, USA), modified Aldrich foot snares, and free-range techniques (i.e., tranquilizing unconfined animals).

Urban-interface bears were captured after conflict complaints received from NDOW dispatch and classified as urban or wildland, dependent upon location of conflict, capture history, and collar data (Lackey et al. 2013). For example, bears were classified as urban or wildland if ≥90% of a bear's telemetry locations were inside or outside of defined urban areas, respectively, as described in Beckmann and Berger (2003a,b) and Lackey et al. (2013). We classified bears captured in wildland areas, and without any known conflict history, as wildland bears (Beckmann and Berger 2003a,b). We classified as unknown any bears that had no capture history but were killed on their first capture event (e.g., vehicle collision, management mortality). Based on location data, collared bears did not switch categories, but all bears likely had some level of access to anthropogenic food sources. All capture methods followed procedures outlined in NDOW's Prescription Drug Policy (2008).We tranquilized bears with a mixture of 4.4 mg/kg Telazol® (Fort Dodge Animal Health, Fort Dodge, Iowa, USA) and 2.2 mg/kg xylazine. From 2003 through 2010, we pulled hair samples ($N = 313$) from the shoulder area of bears, careful to include the root tips. These were then stored in manila coin envelopes frozen at −80°C.

Sample selection

From the 313 hair samples, we removed recaptures within a year of first capture to avoid correlation of samples. We also removed any samples with unknown age or sex. For consistency, all bears were assigned a birth date of 1 February of the birth year. We considered any bear captured prior to 1 August to be a whole year of age and any bear captured after 1 August to be a whole plus half year. This allowed bears <1.5 years to be identified and removed from the analysis because their diet and isotope signatures might be affected by milk from their mother. Bears ≥1.5 years had a full hair-growing season, presumably without mother's milk. Black bears have 2 types of hair—guard hairs and underfur. Based on Asiatic black bear (*Ursus thibetanus*) studies, molt occurs once per year (Mizukami et al. 2005). The underfur primarily starts to grow in autumn for thermoregulation during hibernation and the guard hair starts to grow in late summer, depending on nutrition (C.T. Robbins, Washington State University, personal communication). Hair collected in the late summer–early autumn represents diet from the current season (Mizukami et al. 2005, Teunissen van Manen et al. 2014). We captured bears year-round, so we categorized samples collected from 1 January through 30 June as pre-molt and 1 July through 31 December as post-molt. To avoid potential overlap during midsummer, we removed all samples collected during the month of July.

Sample preparation

We prepared samples using the methods of Teunissen van Manen et al. (2014), which involved washing all hair samples with deionized water in 15- × 45-mm glass vials, drying under a fume hood, and removing oil with a 2:1 chloroform: methanol solution (Acros Organics, Morris Plains, New Jersey, USA; Fisher Chemical, Fairlawn, New Jersey, USA, respectively). We sonicated samples for 15 minutes at 30% amplitude in a water bath using a Fisher Scientific Sonic Dismembrator Model 500 (Branson Ultrasonics, Danbury, Connecticut, USA). We transferred samples to clean glass vials and dried at 40°C overnight.

We selected 3–7 individual strands of guard hair from each sample to obtain an average of the isotope value for an individual bear. We based the number of strands selected on the amount of hair available, density, and length of individual strands. For samples with thicker individual strands, we selected fewer strands, and for samples with thin individual strands, we selected more. We selected hairs that were not broken at the root or tip to ensure we were analyzing the whole hair. We removed the follicle from each hair and placed hair samples into a sterilized (400°C for 3 hr) 5- × 5-cm square piece of foil for cutting. We clipped the hairs into 1-mm segments. We did not use a ball grinder because of the small quantity of hair in several samples. We weighed hair samples (1.3–1.5 mg) in a 5- × 9-mm pressed tin capsule (Costech Analytical Technologies, Inc., Valencia, California, USA). We folded and placed tin capsules into a well tray until all samples were ready for stable isotope analysis in the mass spectrometer.

We collected primary plant-source food items from 2009 through 2011. We opportunistically collected primary vegetation food items during seasons in which bears would be eating those foods. Samples ($n = 57$) included grasses, shrubs, forbs, and trees from various points within our study area. We air-dried samples and then stored them in manila envelopes until ready for analysis. We ground plant materials to filter through a 20-mesh screen and further homogenized them with a ball mill. We obtained the category of human foods used for the mixture model analysis from a review of fast food beef and chicken stable isotopes reported by Jahren and Kraft (2008), which included values for beef and chicken from McDonald's© (Chicago, Illinois, USA), Burger King© (Miami-Dade Co., Florida, USA), and Wendy's© (Dublin, Ohio, USA). We used a category of animal

Table 1. Body mass categories[a] accounting for sex and age group based on a 95% confidence interval for all American black bears (*Ursus americanus*) captured during this study in Nevada, USA, 2003–2010.

Age group (yr)	Sex	*N*[b]	Mean body mass (kg)[b]	SD[b]	95% LCL[c]	95% UCL[c]	Mass category	*N*[d]
1.5–3.0	F				33	47	Below average	6
1.5–3.0	M				32	57	Below average	14
3.5–6.5	F				27	54	Below average	5
3.5–6.5	M				64	108	Below average	16
≥7.0	F				36	66	Below average	12
≥7.0	M				92	141	Below average	11
1.5–3.0	F	19	54	13.8	48	61	Average	6
1.5–3.0	M	42	69	24.8	58	81	Average	14
3.5–6.5	F	17	67	26.7	55	80	Average	10
3.5–6.5	M	51	130	44.1	109	152	Average	24
≥7.0	F	37	81	30.0	67	96	Average	17
≥7.0	M	27	166	49.6	142	191	Average	10
1.5–3.0	F				62	75	Above average	7
1.5–3.0	M				85	106	Above average	14
3.5–6.5	F				81	107	Above average	2
3.5–6.5	M				153	196	Above average	11
≥7. 0	F				97	126	Above average	8
≥7.0	M				191	241	Above average	6

[a] Mass category—To account for differences in body mass associated with age and sex, we constructed 3 categories (below average, average, and above average) using mass and standard deviation for the 6 combinations of age and sex from all recorded bears.

[b] *N,* mean, and standard deviation (SD) calculated by age and sex for all 193 bears originally sampled.

[c] Lower and upper confidence intervals for mass by age and sex.

[d] Sample size for mass category by age and sex.

based on stable isotopes of carbon and nitrogen reported in Hobson et al. (2000) from elk (*Cervus canadensis*), moose (*Alces alces*), mountain goat (*Oreamnos americanus*), mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), and ants (family Formicidae).

Stable isotope analysis

We analyzed stable isotopes of carbon and nitrogen using a Thermo-Finnigan Delta Plus XL (Thermo-Finnigan, San Jose, California, USA), coupled with COSTECH Elemental Analyzer ECS4010 (Costech Analytical Tech, Inc.) at the Stable Isotope Laboratory at the Department of Earth and Planetary Sciences, University of Tennessee, Knoxville, USA. We reported carbon and nitrogen stable isotopes using the δ notation as per mil (‰) with respect to the international stable carbon and nitrogen isotope standards Vienna Peedee belemnite (VPDB) and atmospheric air (Air) as reported in Teunissen van Manen et al. (2014). Standards and validations protocols were described in Teunissen van Manen (2011). We applied a rounded discrimination factor of 2 for carbon and 3 for nitrogen, as reviewed in Teunissen van Manen (2011).

We analyzed food samples at the Washington State University Stable Isotope Lab. Similar to the experiment protocol stated in Teunissen van Manen et al. (2014), we analyzed the samples on a continuous-flow isotope ratio mass spectrometer (Delta PlusXP; Thermo-Finnigan, Bremen, Germany; Brenna et al. 1997, Qi et al. 2003), coupled with an elemental analyzer (ECS 4010; Costech Analytical).

Variable classification

Body mass measurements alone do not account for the overall condition of a bear because of confounding effects of age and sex. To account for differences in body mass associated with age and sex, we constructed 3 categories using the mean mass (average) and 1 standard deviation above mean (above average) and 1 standard deviation below mean (below average) for the 6 combinations of age and sex from all recorded bears (Table 1). We also used sex and age classification as separate variables. We defined 3 age classes of independent bears as 1.5–3.0 years, 3.5–6.5 years, and ≥7.0 years for our analyses because nutritional requirements and experience using anthropogenic foods can vary by age (Beckmann and Berger 2003a). We used urban, wildland, and unknown classifications to assess any differences in food habits by access to human developments (see Sample collection section for description of classification system for urban–wildland).

We handled bears year-round, so we used a season variable to examine any potential differences throughout the year. Season classifications are as follows: winter (1 Dec to 28 Feb), spring (1 Mar to 31 May), summer (1 Jun to 31 Aug), and autumn (1 Sep to 30 Nov). These season classifications are based on assessments of food availability throughout the year (Beckmann and Berger 2003a,b; Lackey et al. 2013). Typically, there are more natural foods available during the late-spring to autumn period than during the winter and early spring periods. We noted that, in our study area, anthropogenic food was available year-round, including during the winter when a lack of natural foods should lead to hibernation (generally from November to April–May; Johnson et al. 2018). As a result of this food availability, we documented bear activity throughout the year, and some bears gaining mass through the winter months because of availability of garbage. A better understanding of seasonal patterns can help target management efforts and resources to reduce potential human–bear conflicts.

We used an information-theoretic approach and developed an a priori suite of linear regression models to examine associations of sex, age class, body mass, molt, season, year, and urban versus wildland classification with stable carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope values (Burnham and Anderson 2002). We constructed design variables for all categorical variables. We used package MuMin (Bartoń 2016), based on Burnham and Anderson (2002; https://cran.r-project.org/web/packages/MuMIn/MuMIn.pdf, Accessed Mar 2017) in Program R (v3.3.1; R Core Team 2016) to conduct the linear regressions, and calculate Akaike's second-order information criterion (AIC$_c$) for small sample size for each model and model-averaging for each parameter. We examined which parameters were associated with variations of carbon (δ^{13}C) and nitrogen (δ^{15}N) isotope values during 2003–2010. We used adjusted R^2 values to evaluate the variation captured with our best model(s). We used regression diagnostics with slope (β) to evaluate the assumptions for linear regression. We used model-averaging to report slope values.

Mixture model methods

We used the R package MixSIAR (v.3.1; Stock and Semmens 2013), which is a Bayesian mixing model, to analyze diet using stable carbon and nitrogen isotopes. We used the urban–wildland–unknown classification as a fixed effect and reported the median and 95% credible interval for each class. Discrimination factors for carbon (mean = 1.75, SD = 1.6) and nitrogen (mean = 3.08, SD = 0.065) were obtained from values reviewed in Teunissen van Manen (2011), but were not rounded to the nearest integer as in the previous analysis, so as to include effects of variability on diet composition. We used 3 categories, including plants (onsite collection), animals (Hobson et al. 2000), and human foods (Jahren and Kraft 2008). We used a normal Markov chain Monte Carlo run length (100,000 chain length with 50,000 burn-in) and evaluated convergence using the Gelman–Rubin Diagnostic.

Results

We sampled 193 black bears from 24 October 2003 through 12 August 2010. We omitted 18 bears sampled in the month of July and 2 bears with unknown body mass. Of the remaining 173 bears, 107 (39 F, 68 M) were classified as urban bears, 24 (13 F, 11 M) as wildland bears, and 42 (15 F, 27 M) were of unknown status. Urban bears had a mean δ^{13}C of −20.18‰ (SD = 1.49) and a mean δ^{15}N of 5.51‰ (SD = 1.30), whereas wildland bears had a mean δ^{13}C of −21.07‰ (SD = 1.49) and a mean δ^{15}N of 4.68‰ (SD = 1.27). Bears of unknown status had a mean δ^{13}C of −20.14‰ (SD = 1.79) and a mean δ^{15}N of 5.47‰ (SD = 1.44).

Our top 3 models for δ^{13}C had 85% of AIC$_c$ model weights (w_i) and included biological (mass category, sex), timing (molt stage), and spatial (urban–wildland–unknown) variables (Table 2). These 3 models (C12, C11, and C8) had AIC$_c$ values $\leq$0.95. All other models had AIC$_c$ values $\geq$3.53 and $w_i \leq 0.06$. Bears in the above-average mass category had enriched ^{13}C compared with the reference class of below-average mass ($\beta = 1.36$, CI = 0.86–1.86; Table 3). Values for δ^{13}C for bears of average mass were not different from those below-average mass (Table 3). Wildland bears had depleted ^{13}C compared with the reference class of urban bears ($\beta = -0.86$, CI = −1.42 to −0.31). Stable isotope values for δ^{13}C for bears of unknown status were not different from bears classified as urban. Finally, δ^{13}C stable isotope values were depleted for hair samples collected postmolting compared with the premolting stage (Table 3).

For δ^{15}N stable isotope values, 2 top models (model N7 and N12) carried 91% of AIC$_c$ model weight and included the variables molt, sex, and mass category (Table 4). All other models had AIC$_c$ values $\geq$6.45. Males had substantially enriched δ^{15}N compared with females (Table 5). For hair samples collected postmolting, δ^{15}N stable isotope values were smaller compared with samples collected during the premolting stage (Table 5).

Table 2. Model-selection results based on second-order Akaike's Information Criteria (AIC_c) to test association of $\delta^{13}C$ stable isotope values with various attributes of American black bears (*Ursus americanus*) in Nevada, USA, 2003–2010.

Model no.	Model description	AIC_c[a]	ΔAIC_c[b]	w_i[c]	K[d]	LL[e]	Evidence ratio
C12	Mass category[f], sex	633.95	0.00	0.36	5	−311.79	1.0
C11	Mass category	634.50	0.55	0.27	4	−313.13	1.3
C8	UW[g] class, molt	634.89	0.95	0.22	5	−312.27	1.6
C14	Mass category, sex, age class	637.48	3.53	0.06	7	−311.40	6.0
C13	Mass category, age class	638.63	4.68	0.03	6	−313.06	12.0
C5	Molt	638.91	4.96	0.03	3	−316.38	12.0
C7	Molt, sex	639.15	5.20	0.03	4	−315.46	12.0
C9	UW class, season	646.70	12.76	0.00	7	−316.01	
C4	Season	649.04	15.09	0.00	5	−319.34	
C6	Season, sex	649.92	15.97	0.00	6	−318.71	
C2	UW class	652.12	18.18	0.00	4	−321.94	
C3	UW class, age, sex	655.76	21.81	0.00	7	−320.54	
C10	Year	656.32	22.37	0.00	3	−325.09	
C1	Age, sex	656.88	22.93	0.00	5	−323.26	

[a] Akaike's Information Criterion adjusted for small sample size.

[b] Difference in AIC_c compared with lowest AIC_c model.

[c] AIC_c model weight.

[d] No. of model parameters.

[e] Log likelihood.

[f] Mass category—To account for differences in body mass associated with age and sex, we constructed 3 categories (below average, average, and above average) using mass and SD for the 6 combinations of age and sex from all recorded bears.

[g] UW class—Urban vs. wildland bears based on Global Positioning System locations and home range of individual bears.

Isotopic signatures of all bears except one fell within the mixing space of diet samples (Fig. 1) and convergence criteria were met. One 2-year-old male bear captured in August 2007 was out of the range of possible $\delta^{15}N$ and $\delta^{13}C$, based on the food items used in the analysis (Fig. 1). Overall however, wildland bears had depleted ^{13}C and ^{15}N compared with urban bears as demonstrated by the mixing models (Fig. 1), indicating they were less likely to access human foods than urban bears. There was great variability in the range of food items used by all categories

Table 3. Parameter estimates of $\delta^{13}C$ using model-averaging for hair collected from American black bears (*Ursus americanus*) in Nevada, USA, 2003–2010.

Variable	Model-averaged parameter estimate	95% LCL	95% UCL
Intercept	−22.39	−23.44	−21.34
Mass category[a] 1 (average)	0.002	−0.43	0.43
Mass category 2 (above average)	1.36	0.86	1.86
Males	0.38	−0.008	0.77
UW[b] Class1 (wilderness)	−0.86	−1.42	−0.31
UW Class2 (unknown)	0.18	−0.27	0.63
Molt 1	−1.12	−1.54	−0.70
Age class (3.5–6.5 yr)	−0.01	−0.48	0.46
Age class (≥7.0 yr)	0.16	−0.32	0.65
Season 1	1.79	0.63	2.94
Season 2	1.06	−0.05	2.16
Season 3	0.74	−0.34	1.82
Year	0.05	−0.07	0.17

[a] Mass category— To account for differences in body mass associated with age and sex, we constructed 3 categories (below average, average, and above average) using mass and SD for the 6 combinations of age and sex from all recorded bears.

[b] UW class—urban vs. wildland bear classification based on Global Positioning System locations and home range of individual bears.

Table 4. Model-selection results based on second-order Akaike's Information Criteria (AIC_c) to test association of $\delta^{15}N$ stable isotope values with various attributes of American black bears (*Ursus americanus*) in Nevada, USA, 2003–2010.

Model no.	Model description	AIC_c[a]	ΔAIC_c[b]	w_i[c]	K[d]	LL[e]	Evidence ratio
N7	Molt, sex	577.84	0.00	0.73	4	−284.80	1.0
N12	Mass category[f], sex	580.69	2.85	0.18	5	−285.17	4.1
N14	Mass category, sex, age group	584.29	6.45	0.03	7	−284.81	24.3
N8	UW class[g], molt	584.54	6.70	0.03	5	−287.09	24.3
N6	Season, sex	584.83	6.99	0.02	6	−286.16	36.5
N3	UW class, age, sex	587.69	9.85	0.01	7	−286.50	73.0
N5	Molt	588.82	10.98	0.00	3	−291.34	
N1	Age, sex	589.05	11.21	0.00	5	−289.34	
N9	UW class, season	590.27	12.44	0.00	7	−287.80	
N11	Mass category	593.10	15.26	0.00	4	−292.43	
N4	Season	593.97	16.13	0.00	5	−291.80	
N2	UW class	594.60	16.76	0.00	4	−293.18	
N10	Year	596.88	19.04	0.00	3	−295.37	
N13	Mass category, age group	597.13	19.29	0.00	6	−292.31	

[a] Akaike's Information Criterion adjusted for small sample size.
[b] Difference in AIC_c compared with lowest AIC_c model.
[c] AIC_c model weight.
[d] No. of model parameters.
[e] Log likelihood.
[f] Mass category—To account for differences in body mass associated with age and sex, we constructed 3 categories (below average, average, and above average) using mass and SD for the 6 combinations of age and sex from all recorded bears.
[g] UW class—Urban vs. wildland bears based on Global Positioning System locations and home range of individual bears.

(Fig. 1), but generally, urban bears had a higher median percentage (increase of 3.8%) of human foods in their diet compared with wildland bears (Table 6). Therefore, location relative to human developments affected the use of anthropogenic food for some, but not all, bears.

Discussion

Based on the top 3 models, the primary factors associated with $\delta^{13}C$ included biological (mass category, sex), timing (molt), and spatial (urban–wildland class) factors. Bears in the above-average mass category had

Table 5. Parameter estimates of $\delta^{15}N$ using model-averaging for hair collected from American black bears (*Ursus americanus*) in Nevada, USA, 2003–2010.

Variable	Model-averaged parameter estimate	95% LCL	95% UCL
Intercept	2.27	1.60	2.94
Molt1	– 0.68	– 1.03	– 0.32
Males	0.74	0.40	1.07
Mass category[a] 1 (Average)	– 0.03	– 0.39	0.34
Mass category2 (Above average)	0.68	0.25	1.11
AgeClass1 (3.5–6.5 yr)	0.05	– 0.36	0.45
AgeClass2 (≥7.0 yr)	0.19	– 0.22	0.61
UW[b] Class1 (Wildland)	– 0.79	– 1.28	– 0.30
UW Class2 (Unknown)	0.04	– 0.35	0.43
Season1	1.09	0.12	2.06
Season2	0.79	– 0.12	1.71
Season3	0.44	– 0.46	1.34
Year	0.11	0.01	0.21

[a] Mass category—To account for differences in body mass associated with age and sex, we constructed 3 categories (below average, average, and above average) using mass and standard deviation for the 6 combinations of age and sex from all recorded bears.
[b] UW class—Urban vs. wildland bear classification based on Global Positioning System locations and home range of individual bears.

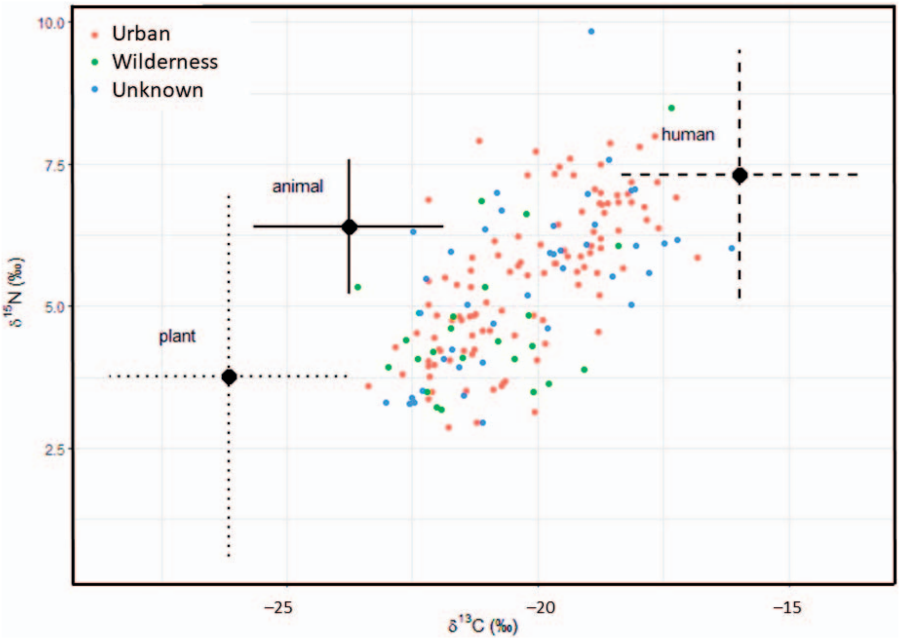

Fig. 1. Mixing space and stable isotope signatures of American black bear (*Ursus americanus*) hair samples and food samples from the Program R package MixSIAR (v.3.1; Stock and Semmens 2013). Hair samples were classified as fixed effects of urban, wildland, or unknown. Food samples were classified using 3 categories: plants (onsite collection), animals (Hobson et al. 2000), and human-derived foods (Jahren and Kraft 2008).

more enriched ^{13}C than those in the below-average mass category. For δ^{15}N, the primary factors included sex and molt and, to a lesser degree, body mass category. Similar to the carbon isotope results, bears in the above-average mass category were more enriched with ^{15}N than bears in the below-average mass category. Mass category and wildland–urban interface (WUI) may have not been as important in predicting enrichment of ^{15}N as ^{13}C because natural foods may vary greatly in protein and nitrogen stable isotopes, whereas enrichment of ^{13}C would be primarily controlled by access to human foods. Access to deer and other wild game and insects could vary, regardless of mass category and WUI location and could greatly affect enrichment of ^{15}N. Teunissen van Manen et al. (2014) also found large variability in δ^{15}N based on natural food availability (specifically hard mast production). In comparison, Hopkins et al. (2012) found only that stable isotopes of nitrogen were useful in predicting food-conditioned bears in Yosemite National Park, California, where there was less human development.

Table 6. Mixing model analysis of the proportions of animal, human-derived, and plant foods in the diet of American black bears (*Ursus americanus*) in Nevada, USA, 2003–2010, using δ^{13}C and δ^{15}N. Animal values were from Hobson et al. (2000), human values from Jahren and Kraft (2008) for beef and chicken, and plant values were from samples collected in Nevada. Discrimination factor from a review by Teunissen van Manen et al. (2011). CI is credible interval.

	Urban[a]		Wildland[a]		Unknown	
Sample	Median	±95% CI	Median	±95% CI	Median	±95% CI
Animal	0.193	(±0.012–0.401)	0.065	(±0.005–0.295)	0.141	(±0.005–0.411)
Human	0.587	(±0.469–0.762)	0.549	(±0.424–0.731)	0.619	(±0.485–0.809)
Plant	0.204	(±0.048–0.401)	0.367	(±0.139–0.524)	0.223	(±0.017–0.430)

[a] Urban vs. wildland bear classification based on Global Positioning System locations and home range of individual bears.

Based on our data, we do not know if heavier bears were more likely to use anthropogenic foods in the form of garbage, or if bears at the WUI were heavier because they use these anthropogenic food sources. We suggest that both explanations contributed. The mixing-space results supported this idea—33% of urban bears were in the above-average mass category and only 7% of wild bears were in the above-average mass category.

We did not consider sex an important variable for $\delta^{13}C$ because the confidence interval of the beta value included 0. However, several studies, including previous work from Nevada (Beckmann et al. 2003a,b), indicate that male bears tend to have increased access to anthropogenic foods and other sources of food with more protein, and thus would have enriched ^{15}N (e.g., Merkle et al. 2011, Johnson et al. 2015). Molt was included in the top model for $\delta^{13}C$ and $\delta^{15}N$, with negative parameter estimates for postmolt hair samples (representative of late spring–early summer diet) relative to premolt hair samples (representative of late summer–early autumn diet) and may reflect greater use of anthropogenic foods in the late summer and early autumn, when bears are typically entering hyperphagia.

Previous studies, including those from western Nevada, have demonstrated that black bears form commensal relationships with humans at the WUI through the use of anthropogenic foods, mostly in the form of garbage (Beckmann and Berger 2003a,b; Beckmann and Lackey 2004, 2008; Merkle et al. 2011, 2013; Lackey et al. 2013; Johnson et al. 2015; Lewis et al. 2015). The result that bears use anthropogenic food sources is not surprising, but the use of $\delta^{13}C$ and $\delta^{15}N$ allowed us to examine the relative prevalence in the diet of these sources of foods compared with naturally occurring wild foods for bears that we had classified behaviorally as urban or wildland. Based on $\delta^{13}C$ and $\delta^{15}N$ analyses, urban bears in western Nevada used both natural and anthropogenic foods, whereas the food habits of wildland bears fell into a tighter mixture space with a greater contribution of natural foods, particularly plants. Bears of unknown classification occupied the entire mixing space of diet samples, suggesting that both urban and wildland bears were included in the unknown classification category.

Johnson et al. (2015) found that bears in drier systems, including western Nevada, selected for areas of human development and anthropogenic foods more consistently than did bears in higher quality habitats. Our results from stable isotope analyses suggested that bears (both those classified as urban and wildland) in the Lake Tahoe Basin and western Nevada had isotope signatures representing elevated ^{15}N and ^{13}C in their diets compared with other more natural areas with American black bear (Hopkins et al. 2012, Teunissen van Manen et al. 2014) or grizzly bear populations (Bentzen et al. 2014) in North America studied in a similar manner.

From a purely physiological perspective, garbage represents an ideal food source for bears; it is predictable in space and time (i.e., garbage is set out the same day of the week, week after week); it is replenished after use (i.e., a bear can eat all the calories out of dumpster and come back the next week and new calories are available, which is not generally possible with wild sources of food); and the discrepancy between the caloric value in dumpsters compared with natural foods in the Great Basin (the driest system in North America where bears are native) probably makes this food source more likely to be used in this xeric environment then in other systems.

The idea that garbage may be the ultimate resource for bears from a physiological perspective has been well-demonstrated in our Lake Tahoe Basin and western Nevada study site, where it has earlier been shown that 1) bears that utilize garbage have increased body mass (a good correlate of fitness [cub production] in bears) compared with wildland counterparts; 2) females utilizing garbage have lower age at first reproduction compared with wildland females; 3) females utilizing garbage have larger mean litter sizes compared with wildland conspecifics; 4) bears foraging on garbage spend less time acquiring food resources on a daily basis compared with wildland conspecifics; and 5) bears foraging on garbage have smaller home ranges (Beckmann and Berger 2003a,b; Beckmann and Lackey 2008). All of these lines of evidence suggest that garbage is a good resource from a physiological perspective because ultimately it leads to high levels of fitness and it is a more reliable resource than natural foods. This is especially true in arid climates that undergo frequent drought cycles, such as our study system. However, even though females utilizing garbage saw an increase in fecundity, their realized reproductive output was actually lower than the number of cubs they produced because most of those cubs were eventually killed in collisions with cars before the age of dispersal (Beckmann and Lackey 2008).

However, not all bears use human foods at high levels, even though they are living near human developments. Just because an individual bear is living in, or adjacent to, the wildland–urban interface does not preclude that bear from foraging on wild foods found within the region in addition to anthropogenic foods. One would expect individual variation to occur in the level of utilization of wild and anthropogenic foods across bears, even within the wildland–urban interface. Bentzen et al. (2014) found that some grizzly bears were considered food-conditioned and some used natural foods, based on their diet from an oilfield region of the Arctic Coastal Plain in Alaska. Individual variation in diet had great management implications because nonlethal methods were not effective in controlling human–bear conflicts for food-conditioned grizzly bears.

We acknowledge that we may have missed some potential wild and anthropogenic food items used by these bears, which could have biased the proportions of anthropogenic, animal, and plant foods identified in our analysis (Phillips et al. 2014). However, taken in totality, the model results for both δ^{13}C and δ^{15}N isotopes suggested that bears in western Nevada exhibit higher and more consistent levels of use for anthropogenic foods in the form of garbage than other systems in North America where stable isotope analyses have been completed (Hopkins et al. 2012, Bentzen et al. 2014, Teunissen van Manen et al. 2014). In addition, our models supported the idea that large male bears tended to use anthropogenic sources of food most often and may have limited use by other sex and age classes. The great variability of human food use by urban and unknown bears was probably indicative that proximity to humans is not always related to actual use of anthropogenic food sources. Our results indicated that, in this xeric system, limiting access to anthropogenic food sources will be critical in reducing human–bear conflict and enhancing coexistence. Future work should further evaluate individual variation and characteristics of bears in urban settings to gain insight into the level at which they use anthropogenic foods.

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Literature cited

Bartoń, K. 2016. MuMIn: Multi-Model Inference. R package version 1.15.6. https: //CRAN.R-project.org/package =MuMIn. Accessed 27 Oct 2019.

Beckmann, J.P. 2002. Changing dynamics of a population of black bears (*Ursus americanus*): Causes and consequences. Dissertation, University of Nevada-Reno, Reno, Nevada, USA.

———, and J. Berger. 2003a. Using black bears (*Ursus americanus*) to test ideal-free distribution models experimentally. Journal of Mammalogy 84:594–606.

———, and ———. 2003b. Rapid ecological and behavioural changes in carnivores: The responses of black bears (*Ursus americanus*) to altered food. Journal of Zoology 261(2):207–212.

———, and C.W. Lackey. 2004. Are desert basins effective barriers to movements of relocated black bears (Ursus americanus)? Western North American Naturalist 64:269–272.

———, and ———. 2008. Carnivores, urban landscapes and longitudinal studies: A case history of black bears. Human–Wildlife Conflicts 2:168–174.

Bentzen, T.W., R.T. Shideler, and T.M. O'Hara. 2014. Use of stable isotope analysis to identify food-conditioned grizzly bears on Alaska's north slope. Ursus 25:14–23.

Brenna, J.T., T.N. Corso, H.J. Tobias, and R. J Caimi. 1997. High-precision continuous-flow isotope ratio mass spectrometry. Mass Spectrometry Reviews 16:227–258.

Burnham, K.P., and D.R. Anderson. 2002. Model selection and multimodel inference: A practical information-theoretic approach. Second edition. Springer-Verlag, New York, New York, USA.

Goodrich, J.M. 1990. Ecology, conservation, and management of two western Great Basin black bear populations. Thesis, University of Nevada, Reno, Nevada, USA.

———, and J. Berger. 1994. Winter recreation and hibernating black bears. Biological Conservation 67:105–110.

Grayson, D.K. 1993. The desert's past: A natural prehistory of the Great Basin. Smithsonian Institution Press, Washington, DC, USA.

Hobson, K.A., B.N. McLellan, and J.G. Woods. 2000. Using stable carbon (δ^{13}) and nitrogen (δ^{15}N) isotopes to infer trophic relationships among black and grizzly bears in the upper Columbia River basin, British Columbia. Canadian Journal of Zoology 78:1332–1339.

Hopkins, J.B., III, P.L. Koxh, C.C. Schwartz, J.M. Ferguson, S.S. Greenleaf, and S.T. Kalinowski. 2012. Stable isotopes to detect food-conditioned bears and to evaluate human–bear management. Journal of Wildlife Management 76:703–713.

Jahren, A.H., and R.A. Kraft. 2008. Carbon and nitrogen stable isotopes in fast food: Signatures of corn and confinement. Proceedings of the National Academy of Science 105:17855–17860.

Johnson, H.E., S.W. Breck, S. Baruch-Mordo, D.L. Lewis, C.W. Lackey, K.R. Wilson, J. Broderick, and J.P. Beckmann. 2015. Shifting perceptions of risk and reward: Dynamic selection for human development by black bears in the western United States. Biological Conservation 187:164–172.

———, D.L. Lewis, T.L. Verzuh, C.F. Wallace, R.M. Much, L.K. Willmarth, and S.W. Breck. 2018. Human development and climate affect hibernation in a large carnivore with implications for human–carnivore conflicts. Journal of Applied Ecology 55:663–672.

Lackey, C.W. 2004. Nevada's black bear: Ecology and conservation of a charismatic omnivore. Nevada Department of Wildlife, Biological Bulletin Number 1. Reno, USA.

———, J.P. Beckmann, and J. Sedinger. 2013. Bear historical ranges revisited: Documenting the increase of a once extirpated population in Nevada. Journal of Wildlife Management 77:812–820.

LeCount, A.L. 1979. Introductory comments. Western Black Bear Workshop 1:1–5.

Lewis, D.L., S. Baruch-Mordo, K.R. Wilson, S.W. Breck, J.S. Mao, and J. Broderick. 2015. Foraging ecology of black bears in urban environments: Guidance for human–bear conflict mitigation. Ecosphere 6:141.

Malaney, J.L., C.W. Lackey, J.P. Beckmann, and M.D. Matocq. 2018. Natural rewilding of the Great Basin: Genetic consequences of recolonization by black bears (*Ursus americanus*). Diversity and Distributions 24:168–178.

Merkle, J.A., P.R. Krausman, N.J. Decesare, and J.J. Jonkel. 2011. Predicting spatial distribution of human–black bear interactions in urban areas. Journal of Wildlife Management 75:1121–1127.

———, H.S. Robinson, P.R. Krausman, and P. Alaback. 2013. Food availability and foraging near developments by black bears. Journal of Mammalogy 94:378–385.

Mizukami, R.N., M. Goto, S. Izumiyama, H. Hayashi, and M. Yoh. 2005. Estimation of feeding history by measuring carbon and nitrogen stable isotope ratios in hair of Asiatic black bears. Ursus 16:93–101.

Nevada Department of Wildlife. 2008. Prescription drug policy. Internal policy and procedure. Nevada Department of Wildlife, Reno, Nevada, USA.

Nevada Forest Industries Committee. 1963. Nevada's forest bounty. Nevada State Library 29-C76F/9:N41.

Phillips, D.L., R. Inger, S. Bearhop, A.L. Jackson, J.W. Moore, A.C. Parnell, B.X. Semmens, and E.J. Ward. 2014. Best practices for use of stable isotope mixing models in food-web studies. Canadian Journal of Zoology 92: 823–835.

Qi, H., T.B. Coplen, H. Geilmann, W.A. Brand, and J.K. Böhlke. 2003. Two new organic reference materials for $\delta;^{13}$C and $\delta;^{15}$N measurements and a new value for the $\delta;^{13}$C of NBS 22 oil. Rapid Communications in Mass Spectrometry 17:2483–2487.

R Core Team. 2016. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/. Accessed Mar 2017.

Stock, B.C., and B.X. Semmens. 2013. MixSIAR GHUI user manual. Version 3.1. https://github.com/brinastock/MixSIAR/. doi:10.5281/zenodo.47719. Accessed Nov 2017.

Teunissen van Manen, J.L. 2011. Using stable isotopes to assess longitudinal diet patterns of black bears (*Ursus americanus*) in Great Smoky Mountains National Park. Thesis, University of Tennessee, Knoxville, Tennessee, USA.

———, L.I. Muller, Z.-H. Li, A.M. Saxton, and M.R. Pelton. 2014. Using stable isotopes to assess dietary changes of American black bears from 1980 to 2001. Isotopes in Environmental and Health Studies 50:382–398.

World Population Review. 2016. http://worldpopulationreview.com/. Accessed 27 Oct 2019.

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