

Foraging ecology of black bears in urban environments: guidance for human-bear conflict mitigation

D. L. LEWIS,^{1,†} S. BARUCH-MORDO,^{1,5} K. R. WILSON,¹ S. W. BRECK,² J. S. MAO,³ AND J. BRODERICK⁴

¹Department of Fish, Wildlife, and Conservation Biology, Colorado State University, Fort Collins, Colorado 80523 USA

²USDA, Wildlife Service, National Wildlife Research Center, 4101 LaPorte Avenue, Fort Collins, Colorado 80521 USA

³Colorado Parks and Wildlife, 0088 Wildlife Way, Glenwood Springs, Colorado 81601 USA

⁴Colorado Parks and Wildlife, 317 W. Prospect, Fort Collins, Colorado 80526 USA

Citation: 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(8):141. <http://dx.doi.org/10.1890/ES15-00137.1>

Abstract. Urban environments offer wildlife novel anthropogenic resources that vary spatiotemporally at fine scales. Property damage, economic losses, human injury, or other human-wildlife conflicts can occur when wildlife use these resources; however, few studies have examined urban wildlife resource selection at fine scales to guide conflict mitigation. We studied black bears (*Ursus americanus*) in the urban area of Aspen, Colorado, USA from 2007 to 2010 to quantify bear foraging on natural and anthropogenic resources and to model factors associated with anthropogenic feeding events. We collected fine-scale spatiotemporal data by tracking GPS-collared bears at 30-min intervals and backtracked to bear locations within 24 hours of use. We used discrete choice models to assess bears' resource selection, modeling anthropogenic feeding (use) and five associated random (availability) locations as a function of attributes related to temporally changing natural (e.g., ripe mast) and human (e.g., garbage) food resources, urban characteristics (e.g., housing density), and land cover characteristics (e.g., distance to riparian area). We backtracked to 2,675 locations used by 24 bears and classified 20% as foraging locations. We found that bears foraged on both natural and anthropogenic food sources in the urban environment, with 77% of feeding events being anthropogenic. We documented inter- and intra-annual foraging patterns in which bears foraged extensively in urban areas when natural food production was poor, then switched to natural food sources when available. These patterns suggest that bears balance energy budgets and individual safety when making foraging decisions. Overwhelmingly, garbage was the main anthropogenic food source that bears used. Selection of foraging sites was not only influenced by presence of garbage but also by proximity to riparian habitat and presence of ripe anthropogenic fruit trees. We found that while 76% of the garbage containers at random locations were bear-resistant, 57% of these bear-resistant containers were not properly secured. We recommend conflict mitigation focus on reducing available garbage and anthropogenic fruit trees, particularly near riparian areas, to make urban environments less energetically beneficial for foraging. Additionally, deploying bear-resistant containers is inadequate without education and proactive enforcement to change human behavior to properly secure garbage and ultimately reduce human-bear conflict.

Key words: American black bear; conflict mitigation; discrete choice models; foraging ecology; garbage management; human-wildlife conflict; resource selection; urban ecology; *Ursus americanus*.

Received 17 March 2015; revised 6 April 2015; accepted 10 April 2015; final version received 16 May 2015; **published** 27 August 2015. Corresponding Editor: D. P. C. Peters.

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⁵ Present address: The Nature Conservancy, 117 E. Mountain Avenue, Fort Collins, Colorado 80524 USA.

† **E-mail:** David.Laurel.Lewis@gmail.com

INTRODUCTION

Urbanization is increasing across the globe (United Nations Population Division 2008) impacting the ecology of many wildlife species (Marzluff 2001, DeStefano and DeGraaf 2003, Shochat et al. 2006, Baker and Harris 2007, Gehrt et al. 2010, Evans et al. 2011). Urban areas offer novel resources to wildlife that are concentrated and predictable in space and time and can alter the ecology of species as they adapt to exploit these resources (e.g., Prange et al. 2004, Rodewald and Shustack 2008, Withey and Marzluff 2009). Use of the urban environment can increase the potential for human-wildlife conflict, resulting in property damage, economic losses, or human injury (DeStefano and DeGraaf 2003, Timm et al. 2004, Kaplan et al. 2011), and the mitigation of conflict is becoming an important aspect of urban wildlife conservation (Conover 1997, Messmer 2000). Because human-wildlife conflict mitigation can be costly to implement (Treves and Karanth 2003), it is essential to understand the ecology of wildlife and how animals select for anthropogenic resources, so that we can better target conflict-management solutions.

Resource selection, defined as the disproportionate use of a resource in comparison to its availability (Johnson 1980), is commonly studied to gain insights on wildlife foraging ecology (e.g., Bakian et al. 2012, Wilson et al. 2012, Marshall et al. 2013). Selection is hierarchical in nature and can vary by spatial and temporal scales (Johnson 1980, Thomas and Taylor 1990, Boyce 2006). The advent of GPS technology for wildlife tracking now allows observations at a fine spatiotemporal scale (Erickson et al. 2001, Thomas and Taylor 2006); however, collection of fine-scale explanatory data remains a challenge as these are often not adequately summarized solely with GIS data (McClure et al. 2012). Understanding selection at these finer scales can provide insights into wildlife foraging behavior and potential management solutions. Examples include the identification of urban areas with high potential for human-coyote (*Canis latrans*) conflict by understanding that even small patches of vegetation provide food sources (Atwood et al. 2004) and focusing education effort toward national park visitors driving mini-vans, because American

black bears (*Ursus americanus*; hereafter black bears) have been shown to select for such vehicles in Yosemite National Park (Breck et al. 2009).

Black bears are opportunistic omnivores that have adapted to long periods of winter food shortage by undergoing hyperphagia, i.e., intensive foraging, prior to winter and then entering a state of winter lethargy with no feeding (Nelson et al. 1983). During hyperphagia, mastling plant species that produce acorns, nuts, and berries provide bears with high caloric energy that is critical for survival and reproduction (Rogers et al. 1976, Inman and Pelton 2002, McDonald and Fuller 2005, Mosnier et al. 2008). But mast crops can fail due to unfavorable weather conditions, e.g., late-spring freezes and droughts (Sharp and Sprague 1967, Neilson and Wullstein 1980), or disease outbreaks (Liebhold et al. 2000), resulting in bears seeking alternative food sources (Baruch-Mordo et al. 2014). Use of anthropogenic food resources can lead to behavioral adaptations and changes to bear ecology (Beckmann and Berger 2003a, Baruch-Mordo et al. 2014) and result in increased human-bear conflict (Oka et al. 2004, Baruch-Mordo et al. 2008). In urban areas, human-bear conflict poses unique challenges as traditional mitigation approaches such as euthanasia, translocation, and hazing can be (1) unpopular among urban residents (Treves and Naughton-Treves 2005, Manfredo 2008, Messmer 2009), (2) ineffective at preventing future conflicts (Beckmann et al. 2004, Landriault et al. 2009), and (3) expensive and time-consuming to implement (Hristienko and McDonald 2007, Fontúrbel and Simonetti 2011). Furthermore, wildlife managers generally agree that compared with bear removal, removing attractants provides a better and long-lasting solution to conflict (Spencer et al. 2007, Baruch-Mordo et al. 2013).

Central to effectively controlling anthropogenic attractants is an understanding of bear resource selection at a fine spatiotemporal scale. In this study, we examined foraging ecology and resource selection by urban bears in Aspen, Colorado, USA (Fig. 1), an urban system that can experience high levels of human-bear conflicts (Baruch-Mordo et al. 2008). We fitted bears with downloadable GPS collars and backtracked to in-town use locations to categorize bear

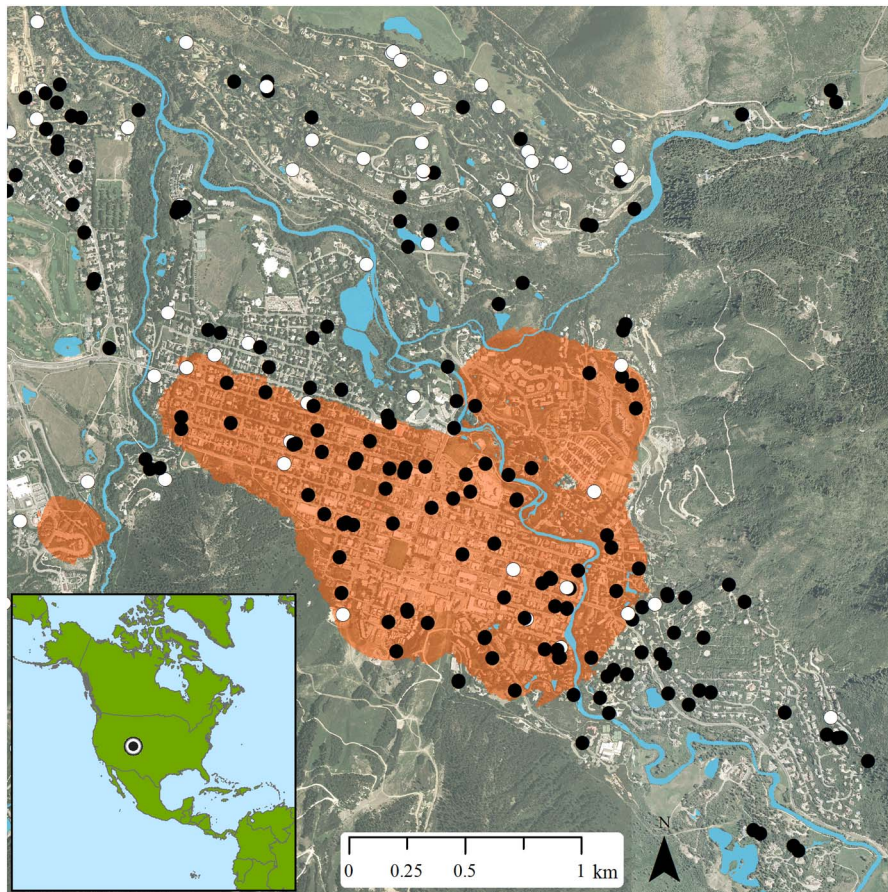


Fig. 1. Black bear foraging locations in Aspen, Colorado, USA, from 2007 to 2010; categorized by foraging events during good (white dots, 2008 and 2010) or poor (black dots, 2007 and 2009) natural food production years. Orange areas indicate high human density corresponding to >200 addresses/km².

foraging on natural and anthropogenic resources during prehyperphagia (1 May–31 July) and hyperphagia (1 August–30 September) seasons of good and poor natural food production years. Using backtracking data our goals were to (1) quantify the number of foraging events that involved natural and anthropogenic food sources, (2) model bear resource selection to identify attributes associated with anthropogenic foraging events, and (3) summarize attributes associated with garbage storage containers and assess their effectiveness in preventing access by bears.

METHODS

Study system

The city of Aspen and surrounding area saw a resident population increase from 8,593 in 2000

to 9,467 in 2010 (United States Census Bureau 2000 and 2010). The city has a central business area that is surrounded by high density residential areas (200–1,200 addresses/km²) composed of apartment buildings and private homes with little or no native vegetation (Fig. 1). Surrounding the city's core area are lower-density neighborhoods and ranch-style estates interspersed with native vegetation (0–200 addresses/km²). Elevation ranged from 2,260 to 3,024 m, with most human development located in the valley bottom and lower-density residential areas located on lower portions of surrounding mountain slopes.

Four mountain valleys converge into the Roaring Fork River that bisects Aspen (Fig. 1). Main landcover types included: mountain shrub

communities (23%) comprised of serviceberry (*Amelanchier alnifolia*), chokecherry (*Prunus virginiana*), and Gambel oak (*Quercus gambelli*); deciduous trees (20%) including aspen (*Populus tremuloides*), cottonwood (*Populus angustifolia*), mountain maple (*Acer glabrum*), and various non-native urban trees; grassland (20%) in the form of mountain meadows and agricultural lands; evergreen trees (12%) comprised of juniper (*Juniperus osteosperma*), pinyon pine (*Pinus edulis*), Douglas fir (*Pseudotsuga menziesii*), spruce (*Picea* spp.), and subalpine fir (*Abies* spp.); developed areas (16%) in the form of buildings, asphalt, and lawn; sagebrush (5%, *Artemisia* spp.); and riparian communities (3%). Natural food production by the key masting species in the study area (serviceberry, chokecherry, and Gambel oak) was poor in 2007 and 2009 and good in 2008 and 2010 (Baruch-Mordo et al. 2014).

The city of Aspen and Pitkin County passed ordinances in 1999 and 2001 requiring proper storage of wildlife attractants (for details see Baruch-Mordo et al. 2011). In 2007, Pitkin County began requiring that garbage be secured in wildlife-resistant garbage containers (Ordinance 020-2007, Pitkin County), and in 2010, the City of Aspen instituted a similar ordinance (Ordinance Sec. 12.08.020, City of Aspen). There were numerous approved garbage container designs that included metal or plastic construction and various securing methods (see descriptions in *Attributes associated with garbage storage* and Appendix A).

Quantifying foraging on natural and anthropogenic resources

Bear capture.—We captured bears in Aspen from May to August 2005–2010 (Colorado State University Animal Care and Use Committee protocols 05-128A-03 and 08-078A-01). We fitted bears with Lotek 4400M GPS remote-downloadable radio collars that were programmed to record locations every 30 minutes during May–September. Following Baruch-Mordo et al. (2014), we used only locational fixes of high quality (PDOP ≤ 5 on 2D fixes and ≤ 10 on 3D fixes).

Backtracking data.—From 2007 to 2010, we monitored 40 bears during their active season (May–September) and backtracked to bear locations using the following methodologies: (1) we

used a randomized list of collared bears to determine backtracking order, (2) we remotely downloaded collar data and backtracked to the most recent 24 hours of location data, (3) we did not backtrack to the most recent location to avoid disturbing the bear, (4) we backtracked only locations within 50 m of building structures because evidence of anthropogenic foraging beyond this distance was not frequent in Aspen (S. Baruch-Mordo, *unpublished data*), and (5) if backtracking to private property, we first obtained permission. When GPS locations were clustered and within 20 m, one location was used to represent all locations. For clusters spanning >20 m, two or more locations were selected to ensure that all bear locations in the cluster were within 20 m of at least one of the sampled locations.

During the study, 42,599 bear locations were obtained within 50 m of structures. Following the sampling criteria specified above, we were able to backtrack to 2,675 bear locations of $n = 24$ bears (10 females and 14 males). At each location a bear used, we searched a 20-m radius looking for natural and anthropogenic foraging evidence. Natural foraging evidence included broken vegetation (e.g., of mast-producing shrubs), disturbed logs, rolled rocks, disturbed soil, animal carcasses, visual observations by persons present during natural foraging, or other miscellaneous indicators of natural foraging. Anthropogenic foraging evidence included scattered garbage, toppled garbage containers, paw prints on attractants, broken limbs of anthropogenic fruit trees such as crabapple (*Malus* spp.), visual observation by persons present during anthropogenic foraging, or other evidence such as broken windows and doors. Using backtracking data we summarized spatial and temporal patterns of foraging events on anthropogenic and natural food sources.

Attributes associated with anthropogenic foraging

Use/availability data collection.—We considered anthropogenic foraging events as use locations and, following a discrete choice sampling design (McFadden 1978), we sampled five randomly selected locations from a circular area centered on each use location. We limited the circular area radii to the average movement distance an individual bear made between relocations in

the previous 24 hours, excluding distances <20 m. Random locations therefore provided a sample of available foraging sites, and allowed spatial and temporal matching between the use (anthropogenic foraging) site and a sample of resources assumed to be available to the bear.

Attribute data.—Because foraging on anthropogenic resources could be opportunistic, we expected bears to select foraging locations in close proximity to travel corridors, in areas surrounded by higher percentages of good bear habitat, i.e., mountain shrub, deciduous forests, and riparian communities (Beck 1991), and when mast and fruit ripen (note that we differentiated between ripe mast, i.e., naturally occurring masting trees shrubs, and ripe fruit, i.e., planted fruit trees such as crabapple). We also expected bears to select foraging sites at an intermediate human density with higher overall anthropogenic attractants but somewhat reduced potential for human interaction (Kretser et al. 2008). Finally, we expected that bears select foraging locations near restaurants, which typically produce large amounts of food waste and emit strong food-scented odors.

We used field sampling and a GIS to collect attribute data to capture the covariates specified in these predictions (Table 1). Field samples were collected within 20 m of each location and, unless specified otherwise, GIS data were summarized within 50 m of locations. Field-collected attributes consisted of local anthropogenic and natural attractants and their availability status including the number of all identified anthropogenic attractants (e.g., barbeque grills, bird feeders, and pet food), presence or absence of secure and unsecure garbage containers, and presence or absence of ripe fruit (i.e., anthropogenic fruit trees) and ripe mast (i.e., acorns, service berries, choke cherries). We determined if mast was ripe based on ripening color specific for each mast species (e.g., blue for serviceberries, dark purple for chokecherries, and brown for Gamble oak). We used geographic data available from Pitkin County GIS Department and high-resolution aerial photos (7.62 cm/pixel) to digitize landcover and summarize GIS attributes. We summarized percent natural bear habitat (% bear habitat) as landcover types associated with mast-producing shrubs and calculated distance to the nearest riparian areas (distance riparian) includ-

ing bodies of water and streams. To quantify human density, we summed the number of addresses that were within 50 m of a location with 5-m grid cells, and then calculated the mean address density within 20 m of each use and availability locations. Finally, we recorded the presence or absence of restaurants.

Resource selection model.—We used a discrete choice model (Cooper and Millspaugh 1999) where the probability of the foraging location being chosen from the set of six locations (one foraging location and five random locations) can be written as

$$p_j(A) = \frac{e^{\beta x A_j}}{\sum_{i=1}^6 e^{\beta x i_j}}$$

where j indexes the foraging event, A is the foraging location, i indexes the set of six locations associated with that foraging event, and x is a vector of location attributes. We estimated β using conditional logistic regression with the clogit function from package *survival* (Therneau 2012) in program R (version 2.14.2, R Development Core Team 2012). We stratified by foraging event so that each foraging location and its associated five random locations were considered a unique stratum, and we accounted for repeated sampling of individual bears using the cluster option in the regression to calculate robust standard errors for coefficient estimates. When clustering by individual, generalized estimating equations were used; thus quasi-likelihoods and an independence model information criterion (QIC) were used to compare models (Pan 2001). We rescaled attribute data of percent bear habitat, distance to riparian areas, and human density by dividing each value by the largest value within each respective attribute to allow for quick interpretation of coefficient estimates (Schielzeth 2010). We ran all possible models to calculate QIC weighted model-average coefficient estimates, 95% confidence intervals, and parameter relative importance values, i.e., the sum of the model weights for models that include the parameter where values closer to one suggest the parameter is an important explanatory variable (Burnham and Anderson 2002). Given that we always ran a quadratic effect of human density, the total model set consisted of

Table 1. Attributes collected near sites of black bear foraging on anthropogenic resources (use; $n = 321$ for 18 bears) and random (availability) locations in the urban area of Aspen, Colorado, USA, from 2007 to 2010. Attributes were used to model selection of anthropogenic resources using discrete-choice models. Predicted and observed relationships are summarized as selection for (+), avoidance (−), indifference (0), or intermediate selection (∩). Parameter estimates were model-averaged over all possible models and are reported with 95% CI as well as each attribute's relative importance values (w_+), the sum of model weights when the parameter was included in the model (Burnham and Anderson 2002).

Parameter	Description	Predicted	Observed	Coefficient	95% CI	w_+
Secure garbage	presence of secure garbage containers	0	+	3.05	1.50, 4.60	1.00
Unsecure garbage	presence of unsecure garbage containers	+	+	4.03	2.40, 5.67	1.00
Ripe fruit	ripe anthropogenic fruit (crabapples, apples, plums, etc.)	+	+	5.14	3.42, 6.87	1.00
Ripe mast	ripe natural mast (serviceberry, chokecherry, oak, etc.)	+	0	0.10	−0.47, 0.68	0.35
% bear habitat	percent landcover considered good bear habitat within 50-m radius of location	+	0	0.0	−0.63, 0.62	0.40
Distance riparian	minimum distance to riparian habitat, rivers, or lakes	−	−	−4.37	−6.18, −2.55	0.96
Human density	averaged 5-m grid cell values within 20 m of location, where cell values are a structure count within 50 m each grid cell	∩	∩	3.88	1.08, 6.68	0.72
Human density ²				−8.75	−14.04, −3.46	0.72
Restaurant	presence of restaurant(s) within 50 m of locations	+	+	1.25	−0.13, 2.63	0.99

255 models.

We used model-averaged coefficients and the global model in a bootstrap k-fold cross validation similar to Fortin et al. (2009); we ran 10,000 iterations of the dataset being partitioned, with 80% of the foraging events being used to estimate the regression coefficients and the remaining 20% used to evaluate model performance. Within each foraging event stratum (i.e., one foraging location and five random locations) we used our model to calculate the relative probability of selection for each location. We then ranked locations based on the relative probability of selection from highest to lowest and determined the frequency that foraging locations across all strata occurred in each of the six ranks (i.e., bins). We report the mean and range of the Spearman rank correlation (r_s) between rank (1–6) and frequency of foraging locations in each rank across 10,000 bootstrap iterations. For comparison we generated an r_s value for random selection by removing the foraging location and randomly selecting one random location to represent the “foraging” location for each choice set, and repeating the ranking process using only five ranks.

Attributes associated with garbage storage

Early in the study, we identified that garbage was a main attractant to bears; hence we collected container design attributes to determine what makes a more effective bear-proof container. We focused on two aspects of container design: (1) its ability to resist bear break-in to obtain food and (2) whether human users were properly securing the container. We classified the container designs into seven categories: (1) top door carabiner, typical garbage container for single family home secured by carabiners located around the container rim, (2) side door carabiner, dumpster with a sliding side door secured by carabiner, (3) top bar, dumpster with a bar placed across the access doors preventing the doors from fully opening, (4) hand latch, mechanism automatically secures container door when closed, (5) rubber sling, flexible material used to secure garbage lid, (6) enclosure, fully enclosed room built around garbage containers, and (7) garbage compactor (see Appendix A for photos and additional descriptions). We used data collected from backtracking to random (available) locations to evaluate the frequency that a container of a given type was properly secured. We evaluated the effectiveness of each container design in preventing bears from obtaining

garbage by comparing the proportion of foraging events where evidence suggested that bears obtained garbage from a secured container (\hat{p}_f) to the proportion that a container type was properly secured at random locations (\hat{p}_r). We tested the null hypothesis $H_0: \hat{p}_r = \hat{p}_f$ versus the alternative hypothesis $H_a: \hat{p}_r < \hat{p}_f$ using a z test

$$z = \frac{\hat{p}_r - \hat{p}_f}{\sqrt{p(1-p)\left(\frac{1}{n_r} + \frac{1}{n_f}\right)}}$$

where n_r and n_f are the sample size for random and foraging location proportions, respectively, and p is

$$p = \frac{x_r + x_f}{n_r + n_f}$$

where x_r and x_f are the number of random and foraging container counts, respectively (Ott and Longnecker 2008).

RESULTS

Quantifying foraging on natural and anthropogenic sources

Overall we classified 122 natural, 397 anthropogenic, and 12 combined natural and anthropogenic foraging events. Even though the number of collared bears being monitored for backtracking was similar from 2007 to 2010, we backtracked more individual bears and found a greater number of anthropogenic foraging events in poor natural food production years of 2007 (events = 169, bears = 11) and 2009 (events = 111, bears = 10) compared to the good natural food production years of 2008 (events = 78, bears = 6) and 2010 (events = 51, bears = 4). The number of anthropogenic foraging events per bear ranged from 0 to 99 and for bears that foraged in town the average was 19.5 (SD = 24.5, $n = 21$). Bears with few foraging events typically lost their collars prematurely, were dispersing males, were only collared during good natural food production years when bears typically remained outside of town, or were removed from the population due to conflict with humans.

Inter- and intra-annually bears switched from foraging on anthropogenic food sources near human developments back to foraging on natural food sources in wildland areas when crops of natural masting plants became available during

the hyperphagia season (Fig. 2). We found that the percentage of bear locations within 50 m of structures from 2007 to 2010, sequentially were 22.7%, 4.7%, 24.1%, and 5.8%; the high percentage years being associated with natural mast failures which occurred in 2007 and 2009. We note that in conjunction with anthropogenic foods, available natural food sources were also used in both year types and seasons within the urban environment. The spatial distribution of anthropogenic foraging events differed in poor and good years with areas of higher human density being used to a larger extent during poor food years (Fig. 1).

Garbage was the most frequently used food source in good and poor natural food production years for both prehyperphagia and hyperphagia seasons (Fig. 2), but we recorded five times fewer garbage foraging events during hyperphagia of good natural food production years. Although garbage foraging events were much greater than all other anthropogenic food sources (Fig. 2), fruit trees and in-home foods (i.e., bear entered structure to obtain food) were the second and third most often used anthropogenic food sources accounting for 6.3% and 5.3% of used attractants respectively. Barbecue grills were commonly found near both bear locations and random locations, but were typically not disturbed by bears. Pet food and bird feeders combined only accounted for 1.2% used food sources, but also only account for 2.3% of attractants found at random locations, so were not a common attractant in the study area.

Attributes associated with anthropogenic foraging

We collected 1,605 available locations for 321 anthropogenic foraging events identified for 18 bears out of the 24 bears in our backtracked sample. Relative importance values indicated that parameters related to secure and unsecured garbage containers, ripe fruit, distance to riparian areas, presence of restaurants were important in the resource selection model (Table 1). The larger regression coefficient of unsecured garbage indicates that bears more strongly selected for locations with unsecured garbage containers than locations with only secured garbage, but both location types were selected for relative to locations with no garbage (Table 1). Bears positively selected for locations with ripe anthro-

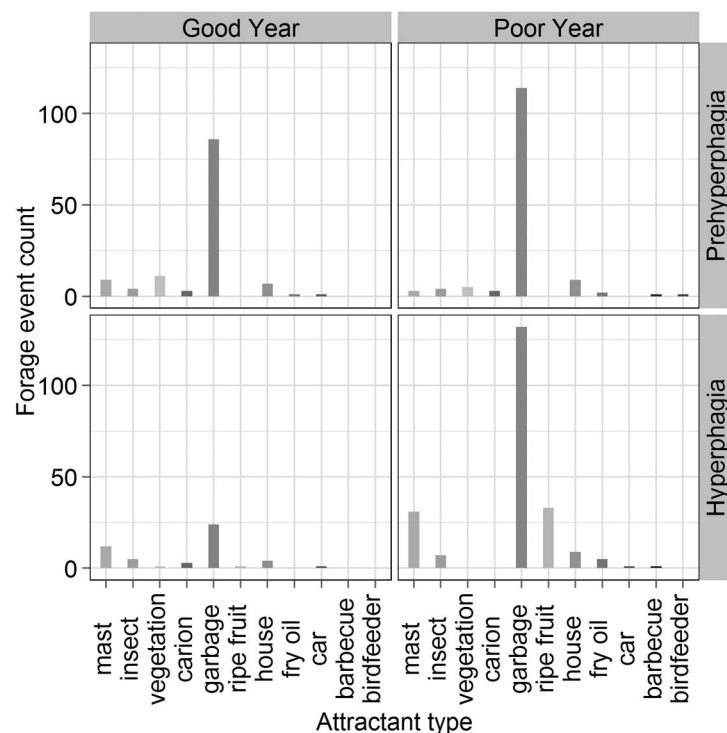


Fig. 2. Number of black bear foraging events with respect to attractant type observed in Aspen, Colorado, USA, from 2007 to 2010. Data were obtained by backtracking GPS-collared bears to foraging locations and are presented by good and poor natural food production years and by prehyperphagia (1 May–31 July) and hyperphagia (1 August–30 September) seasons.

pogenic fruit, and minimum distance to riparian areas had a negative coefficient, indicating areas closer to riparian areas were selected as foraging locations. The coefficient for the second order term of human density was negative indicating that intermediate human density values were selected. The bootstrap k-fold cross validation of the model showed that on average across 10,000 iterations the Spearman rank correlation (r_s) between the proportion of foraging locations in each rank and the rank number (1–6) was $r_s = 0.90$ (0.17–1.0), compared to a model where selection was random where $r_s = 0.004$ (–1.0–1.0).

Attributes associated with garbage storage

We sampled a total of 384 garbage containers at random locations and found 76% to be bear-resistant; however only 57% of bear-resistant containers were properly secured. Residential containers with a top lid secured by carabiners were the most common container type ($n = 124$), comprising 42% of all bear-resistant containers;

these containers also had the second-lowest securing rate with only 48% properly secured (Table 2). At bear locations we found 91 garbage containers where bears obtained garbage from properly secured containers. Dumpsters with a top door carabiner and top-bar securing design made up 69% of observed container failures, allowing bears to obtain garbage even when the container was properly secured. We found that the proportion when a container type was secured at random locations was not significantly less than the proportion when that bears obtained garbage from secured garbage container (z test, Table 2).

DISCUSSION

Bears in Aspen demonstrated behavioral plasticity in their foraging ecology with intra- and inter-annual switching of foraging locations between urban and wildland areas. Switching depended on the availability of natural foods

Table 2. Counts and actual effectiveness of properly secured bear-resistant garbage container designs used in Aspen, Colorado, USA, from 2007 to 2010. To determine if some container designs were ineffective, we compared the proportion that each container type was found secured (\hat{p}_r) to the proportion that each container type failed to prevent a bear from obtaining garbage despite being properly secured (\hat{p}_f). The reported P value compares $H_0: \hat{p}_r = \hat{p}_f$ and $H_a: \hat{p}_r < \hat{p}_f$ using a z test (see *Methods: Attributes associated with garbage storage*).

Securing method	Sampled random locations		Sampled foraging locations		P
	Properly secured count	$(\hat{p}_r)^\dagger$	Properly secured count	$(\hat{p}_f)^\dagger$	
Top door carabiner	60	0.36	32	0.35	0.55
Top bar	46	0.28	31	0.34	0.14
Hand latch	23	0.14	13	0.14	0.45
Enclosure	14	0.08	9	0.10	0.34
Rubber sling	2	0.01	0	0.00	0.85
Side door carabiner	10	0.06	0	0.00	0.99
Other	8	0.05	2	0.02	0.85
Compactor	4	0.02	4	0.04	0.19

† Denominator for proportion calculations is the sum of the respective column count: 167 containers for sampled random locations and 91 containers for sampled foraging locations.

with the greatest shift in foraging behavior occurring during hyperphagia; bears foraged on anthropogenic resources in urban areas during poor natural food years and on abundant natural foods during good food years (Fig. 2). Similar switching in foraging behavior between anthropogenic and natural resources due to changes in natural food availability were reported for other taxa and bears in other systems; for example, herring gulls (*Larus argentatus*) switched from foraging on mussels to foraging on garbage during severe weather years when natural prey was scarce (Pierotti and Annett 1991), and black bears in Minnesota supplemented their diets during poor natural food production years by feeding in garbage dumps (Rogers 1987). However, patterns differed for urban black bears in the Lake Tahoe region where bears continued to forage on anthropogenic resources regardless of natural food availability (Beckmann and Berger 2003b). Unlike Aspen, Lake Tahoe is surrounded by desert basins that provide marginal bear habitat (Beckmann and Lackey 2004); hence we speculate that the difference between Aspen and Lake Tahoe is a result of greater difference in the energetic tradeoffs between urban and wildland areas, such that switching back to foraging in wildlands near Lake Tahoe may not be beneficial.

The plasticity, with shifts by bears between urban and wildland areas, may corroborate a basic foraging ecology theory where costs and benefits associated with foraging are optimized based on individual fitness (Schoener 1971). To reduce the influx of bears into urban areas

especially in poor natural food production years, conflict mitigation strategies can focus on altering the costs and benefits that bears experience in urban areas. Increasing the perceived cost (risk) through common hazing tactics have been found to be ineffective as a long-term solution (Beckmann et al. 2004), potentially because the energetic cost from hazing is small relative to the benefits of food rewards obtained (Baruch-Mordo et al. 2013). A more effective approach may be to direct efforts toward controlling the energetic gains that bears obtain while foraging in urban areas (Baruch-Mordo et al. 2013). Such benefit reduction approach has been successfully implemented in other systems; for example, an aggressive campaign to better secure human-food sources in U.S. National Parks resulted in declines in human-bear conflict in Yellowstone (Gunther 1994) and less human foods in black bears diets in Yosemite (Hopkins et al. 2014). Similarly, better securing of anthropogenic foods from baboons (*Papio ursinus*) in the Cape Peninsula, South Africa, caused a shift from use of anthropogenic foods to other food sources (Kaplan et al. 2011).

Our findings that bears primarily used garbage when foraging in Aspen support a well-established notion among managers that garbage is a major attractant driving human-bear conflict (Spencer et al. 2007). Aspen had much of the infrastructure required to secure garbage, i.e., 76% of garbage containers were bear resistant, but, because of improper use of bear resistant containers and continued use of non-bear proof

containers, over half of the garbage containers provided no resistance to bears. Solely deploying bear-resistant containers will be inadequate without additional resources for education and proactive enforcement to change human behavior such that containers are secured (Baruch-Mordo et al. 2011). Our results also suggest that robust garbage container design is important. Less desirable garbage container designs such as bar top dumpsters did not prevent bears from obtaining garbage even when they were properly secured. This observation may explain why bears selected foraging locations regardless of whether or not garbage containers were secured.

The magnitude of selection of anthropogenic foraging locations in the urban environment was greatest for ripe fruit trees and proximity to riparian areas, followed by unsecured and secured garbage, the primary anthropogenic attractants in the urban area (Table 2). Ripe fruit trees were also the main feeding attractant for bears in Missoula, Montana, USA (Merkle et al. 2013). In Aspen, bears foraged extensively on ornamental crabapple trees used as landscaping in many of the city's public areas. These trees should either be replaced by a non-fruiting variety (e.g., *Malus x*; Gilman and Watson 1994) or sprayed to prevent fruiting. Even at fine spatial scales, anthropogenic foraging was more likely near riparian areas. Similarly in Missoula, Montana, bear conflicts occurred at a disproportionately high rate near riparian areas (Merkle et al. 2011) and in many non-urban studies, bears often select for riparian habitat at a landscape scale (Elowe 1984, Clark et al. 1993, Fecske et al. 2002, Lyons et al. 2003, Obbard et al. 2010). Managers can prioritize these areas for conflict mitigation, e.g., targeted education, and use our understanding of urban wildlife ecology to help further develop solutions to conflict.

Given the plasticity in bear behavior in changing foraging locations depending on the quality of natural foods (i.e., good vs. poor years), reducing conflicts between bears and humans will require long-term commitments from wildlife agencies, municipalities, and urban residents, and engagement of all stakeholders coupled with clear management goals and a willingness to share costs (Redpath et al. 2013). We identified simple measures that can reduce conflict by reducing foraging by bears in urban

areas. In particular, future studies in urban areas should evaluate more effective, e.g., automatic and easily latched by humans, mechanisms for securing garbage and thus reducing anthropogenic attractants, and ultimately the long-term effectiveness of these methods in reducing human-bear conflict. As a generalist species, one size may not fit all black bears. In addition, even in areas such as Aspen, Colorado, climate predictions suggest more frequent extreme weather events such as late spring frosts and droughts (Smith 2011), which can lead to more frequent poor natural food years (Walter et al. 2013). Continuing to understand behavioral adaptations in bear foraging ecology will therefore be important when implementing conservation strategies to ensure co-existence of humans and black bears.

ACKNOWLEDGMENTS

We thank all the private individuals that permitted access to their land and the following groups for funding, logistic support, and personnel support: Colorado Parks and Wildlife, USDA National Wildlife Research Center, City of Aspen and Pitkin County, Aspen Ranger district of the U.S. Forest Service, Aspen Field Biology Lab (AFBL), Aspen Center for Environmental Studies, Berryman Institute, and field technicians. We thank C. L. Burdett, K. R. Crooks, and C. T. Webb for insightful discussion during design and analysis stages of the study. Finally, we thank the Colorado State University Libraries Open Access Research and Scholarship Fund for its support.

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SUPPLEMENTAL MATERIAL

APPENDIX

Photographs of common securing methods used on bear-resistant garbage containers in Aspen, Colorado, from 2007–2010.



Fig. A1. Top door carabiner—Bear-resistant garbage containers secured by clipping carbiners to eyelets along the rim of the container when the top lid is closed. This container is properly secured only when all carabiners are clipped, but is commonly found unsecured when too much garbage is placed in the container preventing proper lid closure and/or when not all carbiners are clipped. Metal containers (left image) are more robust than high-density plastic containers (right image).



Fig. A2. Top bar—Bear-resistant garbage containers secured when a bar is fastened in place over the dumpster lids. A common problem with this design is a heavy metal top lid which is often left open and not properly secured (plastic alternatives are also not robust to bear break-ins). Additionally, missing parts or damage to the bar or lids often rendered these container types difficult to secure. Note: dumpster on the left has been tipped over and garbage pulled out while container remains properly secure.



Fig. A3. Hand latch—Bear-resistant garbage containers secured when a hand latch mechanism automatically engages when the lid is down. These container were often found unsecured when too much garbage was in the container, causing the lid to stay open and fail to latch.



Fig. A4. Enclosure—Bear-resistant garbage containers secured by closed external doors of the structure, which at times allowed for non-bear proof containers to be stored securely inside. There were a variety of enclosure types: fully closed with building-grade constructed walls and metal doors which proved difficult for bears break into (top-left), fully closed with wooden side walls and/or front door, which bears were able to break into (top-right and bottom-left), and semi-open enclosures which were poor in preventing bears from obtaining garbage (bottom-right). There were also many enclosure latching methods including round door knobs (top-left), slide bar (top-right), and drop bar (bottom-left). We note that the most robust enclosure design was a well-constructed room with metal front door and round doorknobs like the enclosure in the top-left panel.



Fig. A5. Rubber sling—Bear-resistant garbage containers secured by a heavy-duty, rubber sling that is stretched over a molded lip. This container was often not secured likely because too much garbage prevented the rubber sling to be properly secured.



Fig. A6. Compactor—Bear-resistant garbage containers secured when a compacting mechanism is locked over the dumpster. These containers are robust, but often had trash placed next to the compactor suggesting that the design of the compacting mechanism may be difficult for some users to operate.