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Best management practices in counting urban black bears

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Abstract: DNA-based capture-mark-recapture (CMR) techniques are commonly used to obtain population parameters of black bears (*Ursus americanus*) in rural and wildland landscapes; however, these techniques have not been implemented in urban clusters (i.e., 2,500 to 50,000 residents). Black bears can readily habituate to urban clusters, and wildlife managers need to monitor and manage these urban bear populations. We modified DNA-based CMR for black bear using hair-snares to take into account the small home ranges of urban bears, urban bear behavior, and human safety within Mammoth Lakes, California, USA. We conducted this study for 3 field seasons in 2010, 2011, and 2012 from June to July. Each field season, we implemented a CMR with 6 encounter occasions, each 7 days in length. We used the traditional corral hair-snare design modified for human safety and chose multiple non-consumable and minimally consumable lure types to prevent food conditioning and a trap-happy response. In 2012, we also tested 3 additional hair-snare designs more appropriate for urban areas: natural rub, haphazard-wire snare, and tennis ball snare. In 2010, we collected an insufficient number of hair samples for CMR by putting hair-snares in the periphery of the urban cluster, which we call the urban–wildland interface. However, in 2011 and 2012, when we put hair-snares in the city center as well as the surrounding urban–wildlife interface and increased hair-snare density, we obtained a sufficient number of hair samples to estimate population density using closed capture CMR models. These adjustments to hair-snaring study design in urban areas helped increase capture and recapture rates to be similar to our wildland area. To achieve high capture rates using hair-snares in the urban area, we put out hair-snares at a density approximately 4 times greater than in our wildland study area and distributed them throughout the entire urban area, and not just on the urban–wildlife interface. In addition, setting hair-snares near anthropogenic features used by bears in urban areas (e.g., culverts, utility poles, dumpsters) and adding spent cooking oil to lures also increased our capture rate. Finally, the corral hair-snare had the highest capture rates of our 4 hair-snare designs. After adapting a study design for hair-snaring wildland bears, our methods were efficient for urban areas, having high capture and recapture rates (>0.30) and good precision for abundance estimates (coefficient of variation <0.2), while maintaining human safety.

Key words: American black bear, California, DNA-based capture-mark-recapture, hair-snare, population estimate, survey technique, urban bear, *Ursus americanus*

DNA-based capture-mark-recapture (CMR) survey techniques using hair-snares have been applied extensively for acquiring population parameters of black bears (*Ursus americanus*). Hair-snare studies can be more cost-effective and less invasive than traditional capturing and marking studies. They obtain more precise and accurate local-scale population parameter estimates than using hunter harvest and mortality data alone (Boersen et al. 2003, Coster et al. 2011). Traditional population parameters obtained with hair-snaring include estimates of sex ratios, population size, and population density (Woods et al. 1999, Robinson et al. 2009, Tredick and Vaughan 2009, Coster et al. 2011). Pederson et al. (2012) used these techniques in a 5-year study of black bears to obtain estimates of apparent survival and temporary emigration in addition to population size utilizing a closed capture robust-design analysis. The same

study also obtained estimates of finite rate of population change and recruitment using a robust-design Pradel model.

Hair-snare studies have been implemented in rural and wildland landscapes for black bears; however, we are unaware of any studies that used hair-snaring to estimate population parameters of black bears that frequent urban clusters. Urban clusters are geographic areas (i.e., communities) that contain 2,500–50,000 people, while rural and wildland geographic areas have <2,500 people (U.S. Census Bureau 2010). It is important for wildlife managers to monitor urban bear populations because black bears in urban clusters can take advantage of anthropogenic resources, habituate to human presence, and become food-conditioned in places where they associate human landscapes with food (Beckmann and Berger 2003*a*, Madison 2008, Merkle et al. 2011). Urban bears can become a threat to public safety and inflict major property damage (Baruch-Mordo et al. 2008, Herrero et al. 2011). In addition, urban environments can negatively affect the health of wildland bear populations by functioning in a source-sink system where the urban environment acts as a sink or ecological trap (Beckmann and Berger 2003*b*, Beckmann and Lackey 2008, Hostetler et al. 2009). Extensive efforts across North America are being made to manage human–bear conflicts and mitigate the negative effects urban environments have on bears.

Our main objective was to obtain baseline population parameters of bears in an urban cluster prior to recommending changes in management actions for bears in the urban cluster (Robinson et al. 2009). We hypothesized that traditional hair-snaring techniques for black bears, as outlined in Woods et al. (1999), needed to be modified for the urban environment due to differences in life history and behavior between urban and wildland bears (Beckmann and Berger 2003*a*) and due to the difficult nature of working in an urban environment (e.g., human safety and private

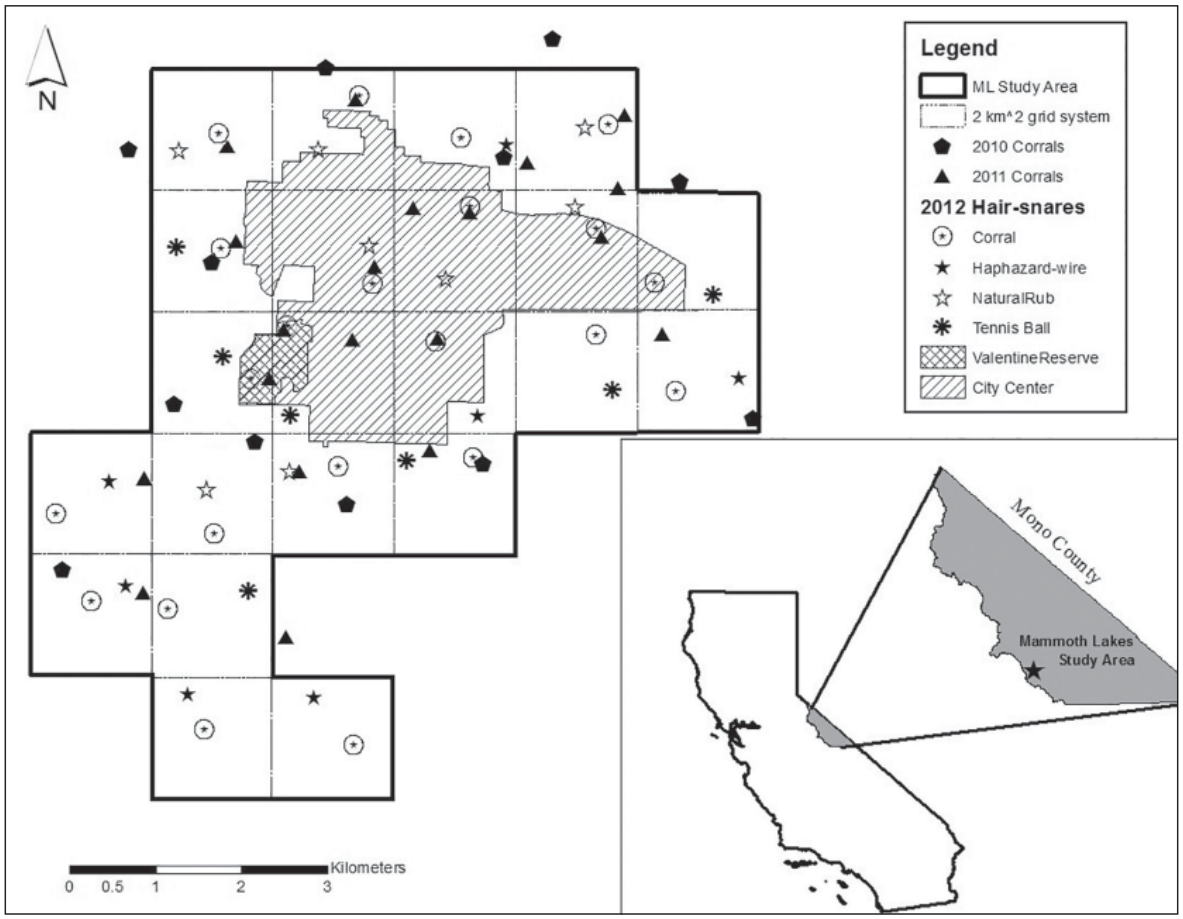

Figure 1. Locations of hair-snares during the urban, black bear (*Ursus americanus*) study in Mammoth Lakes, California, USA, June to July 2010, 2011, and 2012.

property access). Therefore, we evaluated the overall efficacy of implementing a hair-snare study for black bears in an urban cluster as part of the California Department of Fish and Wildlife (CDFW) Mono County Black Bear Project. We hypothesized our study area had a bear population of <50, which, according to White et al. (1982), would require capture probabilities ≥0.3 to obtain reliable closed capture population models. To obtain acceptable precision in our population estimates, we would need to obtain a coefficient of variation (CV) of ≤0.2 (Pollock et al. 1990). Thus, our objective was to ascertain if we could meet these criteria while maintaining human safety in an urban cluster in Mono County, California.

Study area

We conducted our study in the mountain resort community of Mammoth Lakes, California, which has been frequented by black bears for >3 decades (Figure 1). We hypothesized there were 25–30 resident bears in Mammoth Lakes each year. The town of Mammoth Lakes sits at the base of the Mammoth Mountain Ski Resort along the eastern escarpment of the Sierra Nevada, at an elevation of 2,500 m. The community is surrounded by the Inyo National Forest in southwestern Mono County, has 8,234 year-round residents (U.S. Census Bureau 2010), and 1.5 million visitors during the spring and summer, the same time bears are most active (Town of Mammoth Lakes 2007). The municipal city limits contain 60 km^2; while most of the residents (87%) live in the 10-km^2 city center, the remaining 13% live in the 34-km^2 urban–wildland interface (U.S. Census Bureau 2010). Our study area (Figure 1) encompassed only the 44-km^2 area that included the presence of humans (>2,500), anthropogenic resources (e.g., trash), and anthropogenic structures at all times. We assumed the urban–wildland interface had >2,500 people present at all times due to the 1,073 permanent residents and the large number of campgrounds, lodges, resorts, and overall number of tourists staying in the area each summer. The average housing density within the study area was 219 housing units/km^2 (U.S. Census Bureau 2010*b*). All hunting is prohibited within the city limits.

Vegetation types occurring within the city center portion of the study area include fragmented patches of mixed conifer forest, montane chaparral, aspen (*Populus tremulodies*), and willow (*Salix* spp.; Mayer and Laudenslayer 1988). The average annual precipitation is 58 cm (Western Regional Climate Center 2013). In addition to residential and commercial development within the city center, there are also interspersions of open green-ways for recreational use, 2 golf courses, and the Eastern Sierra Valentine Reserve (ESVR). The 0.63-km^2 ESVR is owned by the University of California and provides a refuge for wildlife and facilities for researchers. The urban–wildland interface is dominated by Jeffrey pine (*Pinus jeffreyi*), mixed conifer forest, aspen and montane chaparral. There are 5 lodges/resorts, approximately 20 private cabins, 9 campgrounds, and a network of hiking and biking trails within the urban–wildland interface.

Other mammalian species that could encounter the hair-snares included domestic dog (*Canis lupus familiaris*), domestic cat (*Felis catus*), mountain lion (*Puma concolor*), mule deer (*Odocoileus hemionus*), coyote (*Canis latrans*), and bobcat (*Lynx rufus*).

Methods

We conducted this study for 3 field seasons (2010, 2011, and 2012), which ran from June to July. During each field season, we collected bear hair from hair-snares for a DNA-based CMR (Fusaro et al. 2017). We also collected bear hair opportunistically from dead and captured bears year-round within Mammoth Lakes and throughout Mono County and from bed sites and nuisance scenes only within in the study area during CMR sampling. For the opportunistic samples, our objective was to collect >30 known individual bear hair samples. We used these samples to determine the population genetics (i.e., allele frequencies) of the bears in our study area. We used the data to calculate the probability of identity, probability of exclusion, and similar indices. These probabilities helped the DNA lab determine the likelihood of getting the same genetic profile from 2 different bears (Woods et al. 1999). This whole process was important for obtaining accurate CMR estimates (Waits and Paetkau 2005). The second and third reasons for collecting opportunistic samples were to

Figure 2. Hair sample on a hair corral that is ready for collection. The wire was painted hunter orange for human safety. The study was conducted in Mammoth Lakes, California, USA, June to July 2010, 2011, and 2012.

elucidate movement in and out of the study area and to estimate the number of individuals in Mammoth Lakes that we missed with the CMR methods. The fourth reason for collecting the opportunistic samples was to identify bears that died during the study so we could factor that into our CMR models.

For our 2010 field season, we laid a grid system using 5-km^2 grid cells (n = 12) over the study area. No studies have estimated home range size in our study area; therefore, we determined cell sizes based on the estimates of the home range of bears in the Beckmann and Berger (2003*b*) study of 24 collared, urban black bears (>90% occupancy in an urban area for 10 years) in Lake Tahoe Basin, Nevada with a similar ecotype and towns as Mammoth Lakes. We subjectively reduced cell sizes further with the goal of over-sampling as opposed to under-sampling.

We put 1 hair-snare within each grid cell. The hair-snare design we used was a barbed wire hair corral (single strand) adapted from Woods et al. (1999). Hair corrals were placed only on U.S. Forest Service land surrounding Mammoth Lakes. During 2010, we assumed bears left the city center during the day to seek refuge in the urban–wildland interface. We set up the hair corrals near bear sign (e.g., scat, trails, and tree scratches) and bear travel corridors when possible. For human safety, we painted the barbed wire hunter orange, hung orange flagging every 1 m on the wire, and put up ≥4 signs at each hair-snare in Spanish and English, alerting the public about the wire and potential bear activity in the area.

We placed hair-snares >32 m from roads and trails on public land to reduce the chance of domestic dogs visiting hair corrals while people walked their dogs. We did not place corrals across game trails because we wanted to reduce the number of mixed samples and reduce the chance that deer would knock down the wire and samples. A mixed sample occurs when hair from multiple bears is snagged on the same barb at the same time. We could not genetically differentiate the individual bears from these samples; thus, the sample became unusable.

To entice bears to go over or under the single strand of barbed wire, we placed a non-consumable lure (0.5 L) in the center of each hair corral on a pile of course woody debris. We also sprayed lure on a rag and hung the rag 4 m above the center of each hair corral as an aerial attractant. We used non-consumable, commercial lures to prevent further food conditioning the bears and to thwart a trap-happy response by not providing a caloric reward. Due to the high rate of bears breaking into vehicles in Mammoth Lakes, we stored all lures in bear canisters or metal tool boxes in the bed of field trucks while conducting field work. At each hair corral, we rotated 2 lures systematically to reduce a trap-shy type response by instilling the novelty of a new scent. We chose to use fish oil (Minnesota Trapline Products, Inc., Pennock, MN, USA) and anise (Bear Scents LLC, Lake Mills, WI, USA). We collected hair samples and replenished the lure at each hair-snare once every 7 days for 6 encounter occasions. A short sampling interval was used to minimize violations with demographic and geographic closure for closed population models as well as to reduce sample exposure to ultraviolet light and moisture, which degrade DNA (Kendall and McKelvey 2008).

We used several criteria to determine which samples would be analyzed. A sample consisted of a tuft of hair on 1 barb (Figure 2). We collected all samples with ≥5 bear hairs; however, to reduce analyzing the same individual multiple times during the same session, we collected the samples with the most hairs when bears left multiple samples on adjacent barbs (Tredick

Table 1. Hair sample summary for the black bear (*Ursus americanus*) hair-snare study in Mammoth Lakes, California, USA, June to July 2010, 2011, and 2012.

Year	Hair snare	Samples[a]	Sites[b]	Lab[c]	*Canis* spp.[d]	Bear[e]	Genotype[f]	Failed[g]	Individuals[h]	Unique[i]
2010	Corral	30	10	18[j]						
2011	Corral	81	20	71	7	47	31	33	14	14
2012	Corral	95	22	83	14	69	51	18	28	26
	H-wire[#]	3	7	3	0	3	3	0	2	0
	Natural rub	20	8	18	0	18	18	0	5	4
	Tennis ball	2[k]	7			20[l]				
	Total	118	44	104	14	90	72	18	35	
	Grand total	229	74	175	21	137	103	51	40[*]	44

[a]Suitable samples (≥5 hairs) collected
[b]Sites where hair-snare was applied
[c]Samples sent to the lab after subsampling
[d]Did not differentiate between *Canis* spp.
[e]Samples identified as bear (mixed and samples that amplified only at 1–2 loci were also counted)
[f]Samples successfully genotyped
[g]Includes all samples that failed to genotype, mixed samples, or insufficient amount of DNA
[h]Total individual bears identified with hair-snare type specified
[i]Only bears identified just with hair-snare type specified
[j]Subsampling only, not sent to the lab
[k]<5 hairs, not sent to lab
[l]Total times ball was pulled out and an adequate sample was not left
[*]Adjusted by removing individuals that were identified multiple times
[#]Haphazard-wire

et al. 2007). In addition, we eliminated obvious non-target species samples (e.g., deer) in the field. We sent all the hair samples to the University of California, Davis Wildlife Health and Genetics Lab for DNA extraction and sex and individual identification. See Fusaro et al. (2017) for details on DNA analyses.

In 2011, we sampled in the 10-km^2 city center in addition to the urban–wildland interface because we found bears were using refuges in the city center for extended periods of time (Figure 1). To secure private property access, we presented our project plans to the Mammoth Lakes town council and wildlife management board. In addition to getting access on town property, members of the board put us in touch with numerous private landowners in the community, almost all of whom granted us access to their land to conduct our study. We doubled the number and density of hair corrals (N = 20) for the 2011 field season (Table 1). Due to the spatial distribution of the private property on which we had access, we established a 2-km^2 circular buffer around each hair corral instead of using a grid system. Buffers covered the entire study area with minimal overlap. In addition to using fish oil and anise this field season, we also used hickory smoke and cherry lures (Bear Scents LLC, Lake Mills, Wisconsin). Each lure was randomly assigned to 5 hair corrals and used only at those hair corrals for the first 3 encounter occasions. We only used fish oil for the last 3 encounter occasions.

In 2012, we had sufficient access to private property to place a 2-km^2 grid system with 22 cells over the study area (Figure 1, Table 1). We applied fish oil, anise, hickory smoke, anise with spent cooking oil (50:50 mixture), and hickory smoke with spent cooking oil (50:50 mixture) to the hair corrals. We obtained spent cooking oil from a local restaurant. We randomly assigned lures to hair corrals for the first encounter occasion, and then we rotated

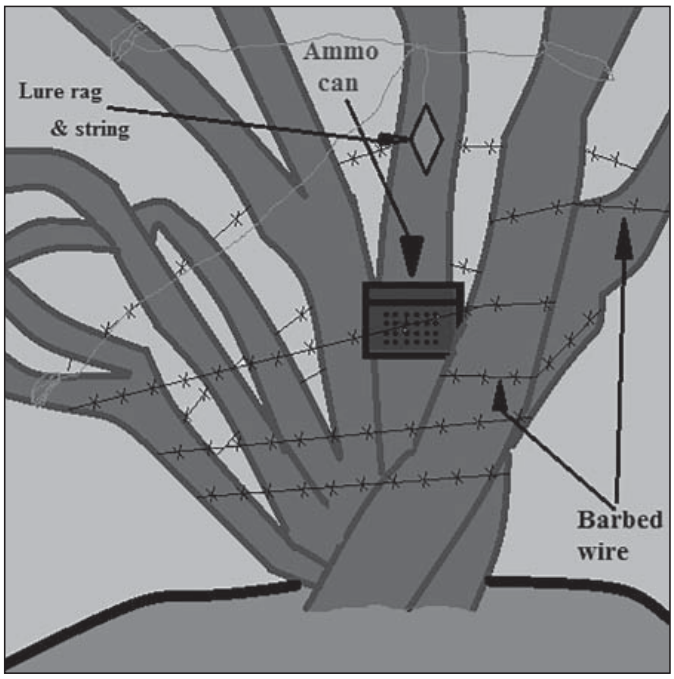

Figure 3. Schematic of the haphazard-wire hair-snare design. There were many scenarios when this design was used. The ammo can was wired to a tree (19-gauge wire). Lure (0.5 L) was put in a bottle with holes in the cap and wired inside the ammo can. Holes were also drilled in the ammo can. Lure was applied to the rag. The barbed wire is set in a configuration that works well to collect bear (*Ursus americanus*) hair. This design was adapted from a similar design by S. Bethune, Alaska Department of Fish and Game, personal communication. The design was tested in Mammoth Lakes, California, USA, June to July 2012.

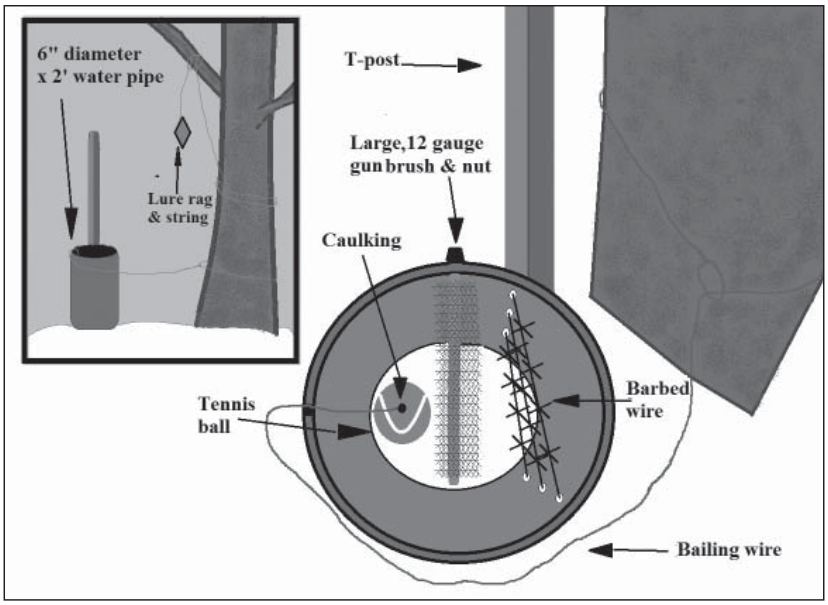

Figure 4. Schematic of the tennis ball hair-snare design. The water pipe was wired to the t-post with 19-gauge wire. Lure was injected into the tennis ball and caulking was used to seal the hole. Lure was also sprayed on the rag. Hair was collected on the gun brush and barbed wire while the bear reached in and pulled out the ball. The design was tested in Mammoth Lakes, California, USA, June to July in 2012.

Table 2. Model averaged abundance estimates, confidence intervals, standard error, capture probability (*p*), recapture probability (*c*), and coefficient of variance from Program MARK for black bears in Mammoth Lakes, California, USA, June to July, 2011 and 2012.

Year	Abundance estimate (N)	95% CI	SE (N)	*p*	*c*	CV (N)
2011	20	17–29	4	0.33	0.33	0.22
2012	46	39–58	7	0.30*	0.31*	0.16

*Capture and recapture for non-corral snares was 0.12.

the lures systematically at each hair corral in a random order for the remaining 5 encounter occasions. Along with adding more lures during 2012, we also added 1 additional hair-snare to each cell. We set up 8 natural rubs (Boulanger et al. 2008), 7 haphazard-wire hair-snares (Figure 3), and 6 tennis ball hair-snares (Figure 4; Table 1). We did this to increase the number of samples collected, reduce capture heterogeneity, and to test hair-snare designs that are safer for use in public areas and required less area for setup.

We used Huggins (1989, 1991) robust-design closed population models, which were similar to Pederson et al. (2012), and model averaging in Program MARK (Lukacs 2010) to obtain population estimates for 2011 and 2012 data. For 2012, we tested additional models similar to Dreher et al. (2007) and Boulanger et al. (2008) that accounted for multiple detection methods in our hierarchical models of abundance. See Fusaro et al. (2017) for more detail on population estimation.

Results

CMR samples

Overall, we collected 229 CMR samples during all 3 field seasons, and 175 samples were submitted for genetic analysis. During 2011, the mean number of bear samples we collected per encounter occasion and per corral hair-snare per encounter was 13.8 and 2.4, respectively, and 18.8 and 3.3 in 2012, respectively. The mean number of individual bears we identified per encounter occasion was 3.7 in 2011 and 8 in 2012. Over the course of both field seasons, we identified a total of 40 individual bears (15 females, 24 males, and 1 unknown sex); 6 bears (3 females and 3 males) were identified in both field seasons (Table 1).

In 2010, we collected 30 hair samples during the 6 encounter occasions, 18 of which were suitable for DNA analysis after subsampling. We assumed those 18 samples would be insufficient for CMR estimates; therefore, we did not have DNA analysis performed on those samples. Numerous bears were seen in the city center during our 6-week sampling period. We decided to establish 2 hair corrals in the city center on the ESVR for 2 additional encounter occasions to test if we were missing bears by only sampling the urban–wildlife interface. During those 2 encounter occasions, we collected 20 hair samples sufficient for DNA analysis. Collecting 20 samples in just 2 sampling periods plus numerous reports of bears seen in the city center drove our decision to set hair-snares in the city center the following years.

A sufficient number of hair samples for CMR was collected in 2011 and 2012 (Table 1). We collected 37 more hair samples in 2012 than in 2011. Genotyping success was 32% higher in 2012 compared to 2011. In 2011, no samples were mixed (i.e., >2 bears in 1 sample) and discarded in the laboratory. We considered samples that did not have enough DNA ($n = 8$) and only amplified at 1–2 loci ($n = 25$) as failures (Table 1). In 2012, there were no samples that did not have enough DNA, 4 samples were mixed, and 14 had degraded DNA (Table 1). Using our a priori models and model averaging in Program MARK (Lukacs 2010), we met our criteria with the 2011 and 2012 data to obtain capture rates of >0.3. The CV obtained from the 2011 data was close to our criteria and within our criteria for the 2012 data (Table 2).

In 2012, we collected 95, 20, 3, and 0 hair samples (N = 118) from the hair corrals, natural rubs, haphazard-wire hair-snares, and tennis ball hair-snares, respectively (Table 1). Nineteen of 22 corral hair-snares were visited

Table 3. A summary of lure visitation by bears (*Ursus americanus*) during the Mammoth Lakes, California, USA field seasons from June to July, 2011 and 2012.

Field season	Lure	Availability[a]	Sites[b]	Samples[c]	Lab[d]	*Canis* spp.[e]	Bear[f]	Failed[g]	Individuals[h]	Unique[i]	Recaptures[j]
2011 (First 3 sessions with all lures)	Anise	15	5	18	16	0	16	2	7	4	1
	Fish oil	15	5	13	11	1	8	6	3	2	0
	Cherry	15	5	2	2	0	2	0	1	0	0
	Hickory smoke	15	5	3	3	0	1	3			
	Total	60	20	36	32	1	27	11	11	6	1
2011 (Last 3 sessions with fish oil only)	Fish oil	60	20	45	39	6	21	21	8	4*	4
2012**	Anise	20	20	11	11	3	8	3	4	3	1
	Anise/spent oil	24	22	19	17	3	14	5	7	3	1
	Fish oil	44	22	32	28	4	24	4	15	8	1
	Hickory smoke	15	14	3	2	1	1	1			
	Hickory smoke/ spent oil	29	22	30	24	3	21	2	11	7	1
	Total	132	100	95	82	14	68	15	37	21	4

[a]Available sessions where lure was applied
[b]Sites where lure was applied
[c]Suitable samples (≥5 hairs) collected
[d]Samples sent to the lab after subsampling
[e]Did not differentiate between *Canis* spp.
[f]Samples identified as bear (mixed samples and samples identified at >1 locus but did not fully genotype were also counted)
[g]Includes all samples that failed to genotype due to DNA degradation, mixed samples, or insufficient amount of DNA
[h]Individual bears identified
[i]Individual bears only identified at the lure specified
[j]Recaptures of the same individual bear
*Not identified in previous 3 sessions
**Just corral design

Table 4. Summary of visitation to corral hair-snares by individual identification (ID), sex, year, and non-consumable lure type for an urban black bear study in Mammoth Lakes, California, USA, June to July, 2011 and 2012.

ID	Sex	Year	Anise	Anise/ spent oil	Cherry	Fish oil	Hickory smoke	Hickory smoke/ spent oil
1	M	2011	1	*	0	1	0	*
2	M	2011	1	*	0	7	0	*
3	M	2011	0	*	0	2	0	*
4	M	2011	0	*	0	2	0	*
5	F	2011	1	*	1	0	0	*
6	F	2011	0	*	0	1	0	*
7	F	2011	0	*	0	1	0	*
8	F	2011	0	*	0	2	0	*
9	F	2011	2	*	0	0	0	*
		2012	2	2	*	1	0	2
10	F	2011	1	*	0	1	0	*
		2012	0	0	*	0	0	1
11	F	2011	0	*	0	2	0	*
		2012	0	0	*	2	0	0
12	M	2011	1	*	0	0	0	*
		2012	0	0	*	1	0	0
13	M	2011	1	*	0	4	0	*
		2012	0	0	*	0	0	0
14	M	2011	0	*	0	4	0	*
		2012	0	1	*	1	0	0
15	M	2012	0	1	*	1	0	0
16	M	2012	0	0	*	1	0	1
17	M	2012	0	0	*	1	0	1
18	M	2012	0	0	*	0	0	1
19	M	2012	0	0	*	1	0	1
20	M	2012	0	0	*	0	0	1
21	M	2012	0	0	*	0	0	1
22	M	2012	0	0	*	1	0	0
23	M	2012	0	0	*	1	0	0
24	M	2012	0	1	*	0	0	0
25	M	2012	0	0	*	0	0	1
26	M	2012	0	0	*	0	0	1
27	M	2012	1	0	*	0	0	0
28	M	2012	1	0	*	0	0	0
29	M	2012	0	0	*	0	0	1
30	F	2012	0	0	*	1	0	0
31	F	2012	1	0	*	0	0	0
32	F	2012	0	0	*	1	0	0

Table 4 continued.

33	F	2012	0	1	*	1	0	1
34	F	2012	0	1	*	0	0	0
35	F	2012	0	0	*	1	0	0
36	F	2012	0	0	*	1	0	0

* Lure not used during that year

by a bear at least once, and >1 bear hair samples were collected, as were 4 of 8 natural rubs, 3 of 7 haphazard-wire snares, and 0 of 6 tennis ball snares. In 2011, all corral hair-snares were visited by a bear and ≥1 hair samples were collected.

Lure summary

We collected ≥1 bear hair sample with each lure type. Cherry and hickory smoke worked poorly to attract bears. Bears were more attracted to lures with spent cooking oil added as opposed to lures that did not have spent cooking oil added. Interestingly, hickory smoke without spent cooking oil attracted 0 bears in 2012, while hickory smoke with spent cooking oil attracted 11 individual bears and was the second best lure. During the first 3 sampling sessions of 2011, we collected the greatest number of bear samples from anise (N = 16) and fish oil (N = 8). In 2012, anise and fish oil continued to do well, luring 4 and 15 bears to corral hair-snares. We defined lure availability as the number of site-sessions (i.e., number of sites × number of sessions). In 2012, the highest proportion of bears captured per lure availability was with hickory smoke with spent cooking oil (0.724), followed by anise and spent oil (0.583), fish oil (0.545), anise (0.400), and hickory smoke (0.067; Table 3). Of the bears that were identified >2 times, 12 bears were attracted to multiple lures, and 7 bears were attracted to 1 lure type. Two of the 6 individuals identified in both years and identified >2 times switched from visiting the same lure 1 year to visiting multiple lures the other year (Table 4). Canids (likely domestic dogs) were attracted to all lure types.

Opportunistic samples

We collected 65 opportunistic hair samples throughout Mono County, California and sent them to the DNA processing lab; 29 samples were from known bears (28 dead and 1 captured bear) and 36 samples were collected in the Mammoth Lakes study area not from known bears (e.g., bed sites and scenes of human–bear conflicts). Of the known bear samples, 4, 11, and 14 samples were from 2010, 2011, and 2012, respectively. Genotyping success was 81% for the unknown bear samples and 97% for the known bear samples. In support of our lab methods, all 28 known bear samples were correctly identified to the individual bear.

Five of the known (reference) bear samples were collected in the study area (4 dead and 1 captured bear). These bears were not identified in the CMR, and no bears identified in town were also identified outside of the study area. In addition, none of the dead bears died during the periods of CMR, which helps support the assumption of demographic and geographic closure for closed population models. We identified 20 bears from opportunistic samples in the Mammoth Lakes study area. We identified 8 bears in both opportunistic and CMR samples (3 in 2011 and 5 in 2012). We identified 11 bears from opportunistic samples in the study area that were not identified from hair-snares (3 in 2011 and 8 in 2012).

Discussion

Black bears readily habituate to urban landscapes (Beckmann and Berger 2003*b*), and human–bear conflicts are increasing in many areas (Peine 2001, Beckmann and Berger 2003*a*, Beckmann et al. 2004, Baruch-Mordo et al. 2008). The negative effects urban landscapes can have on local bear populations are a serious management concern (Beckmann and Lackey 2008, Hostetler et al. 2009). One of the first steps in making informed management decisions is to obtain population parameters of the local population of interest (Thompson

et al. 1998, Williams et al. 2002). To our knowledge, no one has acquired population parameters of bears that frequent urban clusters using DNA-based CMR techniques. We successfully developed DNA-based CMR techniques to acquire population parameters of bears that inhabit urban clusters.

Setting hair-snares in the city center in addition to the urban–wildland interface, establishing ≥1 hair-snare per 2 km^2, and using multiple non-consumable lure types worked to provide sufficient sample sizes and obtain high enough capture and recapture rates (>0.3) to estimate population parameters in this study area with high precision (CV < 0.2; Table 2). The noninvasive nature of this project was appealing to the public. In addition, there were no reports of the public, pets, or bears being harmed by the hair-snares. All of our criteria for a successful survey of an urban black bear population were met. The techniques that this study developed to survey urban black bears noninvasively can be used as a model for similar studies throughout North America where bears spend the majority of their time (> 90%) in urban clusters.

One of the important aspects to a successful wildlife study in urban areas is public acceptance. Lord and Cheng (2006) highlight the major barrier to public involvement (i.e., allowing private property access) is the public's lack of understanding of how state wildlife agencies make management decisions. Furthermore, public involvement improves studies through cooperation. Securing private property access was the most challenging yet essential tasks of this study. It was critical that we earned the public's trust and respect to obtain private property access. We gained that trust and respect by being transparent and presenting our science-based management goals and objectives at town council meetings. In addition, we presented our final results to the general public and encouraged local media to summarize our findings. Furthermore, we always took the time to speak with the public while doing fieldwork. These relatively simple acts often resulted in property access to establish hair-snares the following year and to search for opportunistic samples.

We suggest having town council members and well-known community members help gain access to private property. Some private landowners had us sign documents stating exactly what we would and would not do on their property. Painting the barbed wire hunter orange, hanging orange flagging every 1 m on the barbed wire, and putting ≥4 signs in Spanish and English around the hair-snares were simple yet effective safety modifications. People were more inclined to allow these snare devices on their property because they were highly visible and risk of injury was reduced. Establishing a good relationship with local law enforcement was also beneficial because we were able to collect hair samples from scenes of human–bear conflicts where the officers responded. Future studies may benefit from getting approval to establish hair-snares on utility company property. Utility companies often own property that is well distributed in a community. Bears often rub on utility poles and seek refuge in culverts. Hair-snares can be placed on or near these attractants.

Numerous DNA-based CMR bear studies have obtained higher capture and recapture rates and consequently lower CV than our study by using consumable baits (Immell and Anthony 2008, Gardner et al. 2010). Using consumable baits may have improved our recapture rates and lowered CV, but our protocol minimized further food conditioning the bears in the urban clusters. There may have been some caloric reward for the bears from the fish oil and spent cooking oil; however, we believe these effects were negligible. Bears chewed on wood and dug up the ground where these lures were placed. Our lure results are similar to those found in Pederson et al. (2012) where bears preferentially visited hair-snares with anise and fish oil. However, it appears as though urban bears are also attracted to lures with spent cooking oil. Cooking oil may be sought after in Mammoth Lakes because bears may be familiar with this substance due to frequent access to spent cooking oil spilled on outdoor storage tanks.

The corral hair-snare design worked best to collect bear hair samples; however, corral hair-snares take up a lot of space. Space is limited in urban clusters. Though the alternative hair-snare designs were not as effective as the corral hair-snare, they have their advantages over the corral design. The

haphazard-wire hair-snare, natural rub, and tennis ball hair-snares can be set up easily by 1 person in less time than other designs. They also take up less space than the corral design. Requiring less space increases flexibility when setting up the hair-snares on private land. The tennis ball hair-snare is a single-catch design; therefore, mixing of samples is unlikely. The tennis ball hair-snare can easily be set up next to anthropogenic attractants (e.g., dumpsters), and DNA degradation from ultraviolet light is minimized because direct sunlight is minimized. In spite of the advantages, the tennis ball hair-snare design was not successful at obtaining adequate hair samples (≥5 hairs). The ball was pulled out of 4 tennis ball hair-snares a total of 20 times; only 2 samples were left and those 2 samples did not have a sufficient amount of DNA to analyze. Hence, we cannot recommend the use of our tennis ball hair-snare design to collect hair from bears.

Management implications

We developed protocols and study design modifications that make estimating urban bear population abundance and vital rate parameters feasible. Prior to this study, population parameters of black bear in habitat types similar to Mammoth Lakes had not been monitored using noninvasive, DNA-based CMR. Urban bear populations may occur at higher densities than surrounding wildland or rural habitat akin to what occurs in Mammoth Lakes. To adequately measure urban bear population parameters, the density of hair-snares must coincide with the bear density estimate, which may be 4 times greater than the surrounding wildland habitat. Hair-snares should be placed in the entire urban area including the city center to adequately survey the urban bear population. We recommend using the traditional corral hair-snare design, but for human safety, also paint the wire hunter orange, hang orange flagging every 1 m on the wire, and post signs in the local languages around the hair-snares. In addition, we recommend rotating oil-based lures at the survey stations and placing hair-snares in close proximity to anthropogenic features such as culverts, dumpsters, cooking oil bins, and power poles to improve capture and recapture rates. The modifications we made to traditional DNA-based hair-snaring for black bears in wildland areas are useful in urban areas for long-term population monitoring or as part of a Before-After-Control-Impact analysis when evaluating management actions.

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