Human–Wildlife Interactions 11(2):133–145, Fall 2017

Evaluating lethal and nonlethal management options for urban coyotes

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Abstract: Human–coyote (*Canis latrans*) conflict in urban environments is a growing issue in cities throughout the United States, with the primary problem being the development of problem individuals that are overly bold and aggressive with people and pets. Little research has focused on management options to deal with this conflict. We better define lethal and nonlethal management strategies associated with proactive and reactive management of coyotes with an emphasis on management of problem individuals. We then provide data from research in the Denver Metropolitan Area (DMA), Colorado, USA that focused on reactive lethal removal of problem coyotes and reactive nonlethal hazing (i.e., community-level hazing, a commonly recommended strategy that we better define). The primary lethal management strategy being used in the DMA is to remove problem coyotes only when severe conflict (primarily threats to people) occurs. From 2009–2014, there were 27 removal events (4.5/year) with the average number of coyotes removed per event being 2.1 (range 1–11) and the average number of coyotes removed per year being 9.3. The estimated percentage of coyotes removed per year from the population was between 1.0 and 1.8%. We also measured recurrence of conflict (i.e., length of time until another severe conflict occurred in the vicinity of a removal event) as a measure of efficacy. Of the 27 removals, there were 9 with recurrence with an average of 245 days (range 30–546) between removals, and 18 events without recurrence and with a mean time since conflict event of 1,042 days (range 133–2,159). For our community-level hazing experiment, we used wildlife cameras to record activity of both people and coyotes at 4 sites (2 treatment and 2 control). At treatment sites with a prior history of conflict, we educated and encouraged people to haze visible coyotes and hypothesized that hazing would decrease the activity overlap between people and coyotes on treatment sites. We recorded >50,000 independent sightings of people and coyotes and found activity overlap between humans and coyotes to be either similar or greater on treatment sites compared to control sites. Our results indicate that reactive nonlethal hazing as conducted in this study was ineffective in reducing human–coyote activity overlap. However, due to a variety of reasons we detail below, we encourage readers to interpret the hazing results with caution. We conclude that reactive lethal removal of problem individuals is an effective means of managing conflict and that proactive nonlethal strategies are critical as well.

Key words: *Canis latrans*, community-level hazing, conflict recurrence, Denver, hazing, population, problem individual

Urbanization is altering landscapes worldwide and creating novel environments for species that are able to adapt to the urban matrix (Czech et al. 2000, McKinney 2002). Coyotes (*Canis latrans*) epitomize a successful urban adapter (Gerht et al. 2009), having colonized nearly every major city in the United States (Poessel et al. 2017). Generally, urban coyotes coexist with people in urban environments without causing conflict, but occasionally individuals (i.e., problem individuals) within a population will show extreme forms of bold and aggressive behavior (see Baker and Timm 1998, Timm et al. 2004) that results in conflict, primarily in the form of attacks on pets in the presence of people and occasionally people (Poessel et al. 2013).

City, county, and state officials must make decisions about how to manage conflict, and these decisions generally try to balance the welfare of coyotes, the effectiveness of management actions, and the desires of the

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Table 1. Conceptual model of the 4 different management options available for reducing human–coyote (*Canis latrans*) conflict in urban areas. This model does not consider any strategies that involve large-scale population reduction efforts.

	Proactive management	Reactive management
Lethal	Removal of urban coyotes prior to the onset of severe conflict. Selective removal is generally based on behavioral profiling and occurs year-round and throughout a broad area.	Removal of urban coyotes after severe conflict occurs. Removal efforts are focused at the location of conflict with the goal of removing the individual or individuals causing conflict.
Nonlethal	Altering the behavior of coyotes prior to the onset of conflict. The effort usually involves some form of hazing or other aversive conditioning and is focused on all coyotes in a particular area.	Altering the behavior of coyotes after severe conflict occurs. The effort is focused on altering the behavior of specific problem individuals through hazing or other aversive conditioning.

public. Little research has been conducted that can help managers and the general public make more informed decisions about managing urban coyote conflict (exceptions are Baker and Timm 1998, Timm et al. 2004, White and Delaup 2012). Our goal was to help rectify this gap in knowledge by first elucidating the management options available, providing results from efforts to evaluate management strategies, and providing our collective opinion about best management practices. Specifically, we first define 4 conceptual management strategies that are available to manage urban coyote conflict that involve proactive or reactive efforts and lethal or nonlethal strategies (Table 1). We then provide results from 2 efforts to reduce human–coyote conflict.

In our conceptual model, both lethal and nonlethal options are labeled as either proactive (i.e, management actions implemented prior to onset of conflict) or reactive (i.e., management actions implemented after conflict has occurred). Critical to these strategies is the concept of problem individuals (Linnell et al. 1999), whereby certain individuals within a population are more prone to cause conflict than others. This notion of problem individuals in urban coyotes is supported in many study systems (Timm et al. 2004, Gerht et al. 2009, White and Gehrt 2009, Lukasik and Alexander 2011, Poessel et al. 2013) throughout the United States. Existence of problem individuals implies that wide-scale removal efforts aimed at reducing the population density of coyotes will likely have a low benefit–cost ratio for reducing conflict and have greater public opposition given the generally moralistic attitudes of urban residents toward coyotes (Kellert 1984). Thus, our conceptual model does not include any options associated with wide-scale coyote population removal efforts in urban settings, similar to the recommendation of McNeill et al. (2016) for urban dingoes (*Canis lupus dingo*).

In the case of lethal removal, proactive strategies are based on behavioral profiling, where individuals are removed by profiling bold or aggressive individuals or other behavioral traits that presumably correlate to potential problem individuals. In contrast, reactive lethal management takes the strategy of waiting until conflict occurs and then selectively removing individuals causing conflict. Nonlethal strategies can also be either reactive or proactive. Similar to lethal strategies, reactive nonlethal strategies target problem individuals and generally involve some type of aversive conditioning, with the goal of altering the behavior of the problem animal. These efforts usually involve intense efforts over short periods of time (weeks to months). Proactive nonlethal strategies differ somewhat in that the focus is on preventing the development of problem individuals and therefore must target the population instead of certain individuals. Proactive nonlethal strategies especially rely on educating affected stakeholders to alter their own behavior that then helps prevent the development of problem individuals. Coyote populations typically have both resident and transient individuals within the population (Bekoff and Wells 1981). Conceptually, proactive nonlethal strategies might be most appropriate for stable, resident coyotes because nonlethal efforts could be more easily applied repeatedly to the same individuals over time. In contrast, reactive strategies (both lethal and nonlethal) may be more effective for transient or dispersing individuals causing problems.

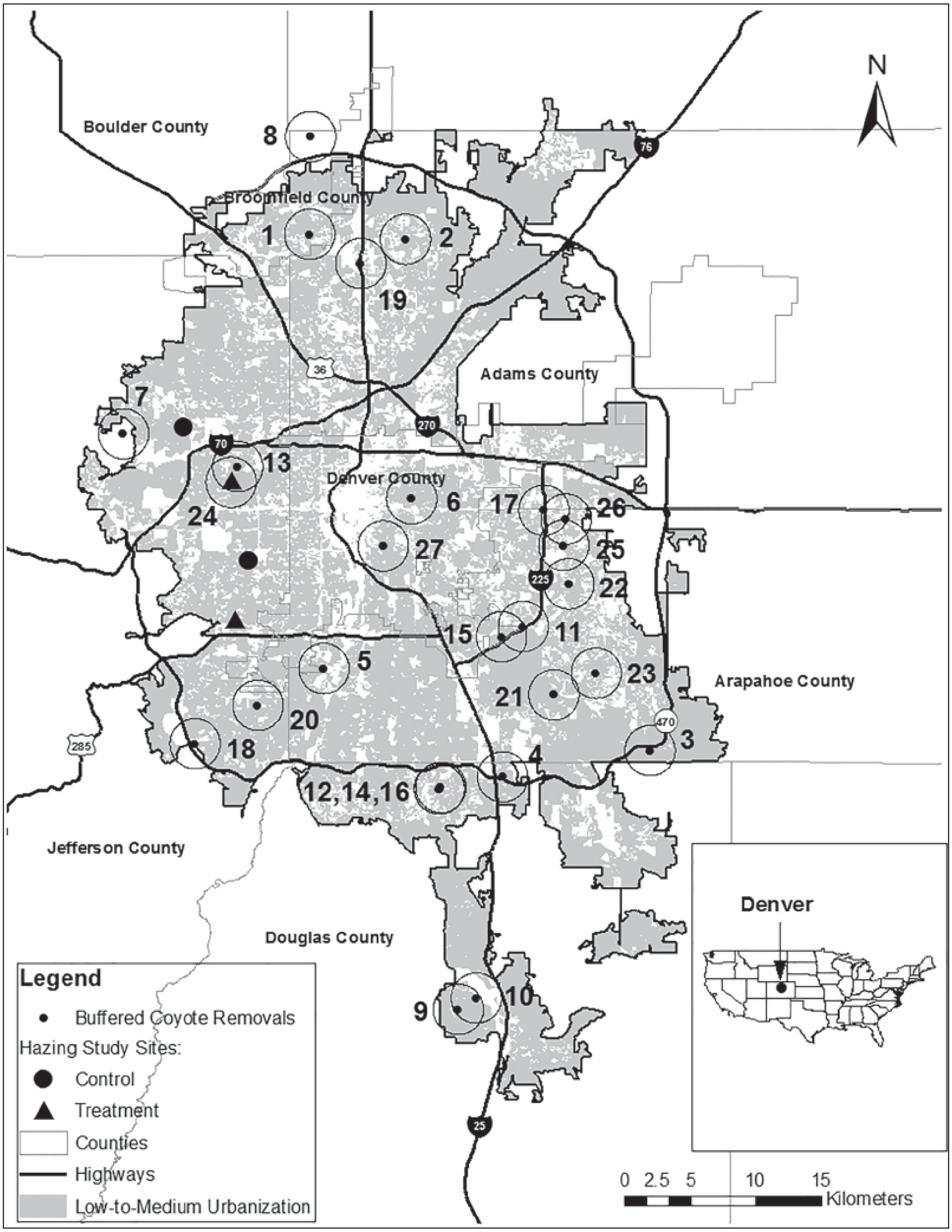

Figure 1. Map of the Denver Metropolitan Area, Colorado, USA, showing the boundary we used to estimate the number of coyotes (*Canis latrans*). In addition, treatment and control sites from the hazing study conducted in 2014 are designated on the map as well as lethal control actions that occurred from 2009–2014 (numbers correspond to IDs of Removals in Table 2). The buffers around the points of coyote removals represent the average home-range size of resident coyotes (i.e., 11.6 km^2).

However, this level of detail is speculative, especially considering how little is known about any strategy.

We used this model to help guide efforts for reducing coyote conflict in an urban environment. We focused on evaluating two strategies, reactive lethal and reactive nonlethal control of problem coyotes. The rise of aggressive behavior in urban coyotes is speculated to derive from the way the public interacts with coyotes in urban environments and a general lack of consequences for being in the presence of humans (Baker and Timm 1998, Bonnell and Breck 2017). Management strategies commonly proposed to reduce conflict involve removing problem individuals and educating the public to aversively condition coyotes. In this context, we 1) investigated the effectiveness of reactive lethal control of problem individuals for reducing conflict by estimating time to recurrence of severe conflict and then evaluating the potential impact of removal efforts on the coyote population, and 2) evaluated the effectiveness of a form of aversive conditioning (i.e., community-level hazing) for altering behavior of problem coyotes to avoid activity overlap with humans and human-rich areas. Approval to undertake this project was granted by the USDA-NWRC Institutional Animal Care and Use committee (QA-1972), and the project was conducted in accordance with this approval.

Methods

Study area and coyote management

We conducted our work within the Denver Metropolitan Area (DMA; see Poessel et al. 2013 and 2016 for more detail). Importantly, we defined the area of the DMA based on how the U.S. Census Bureau defined the Denver urban area in 2010 with a total area of 1,764 km^2 (Figure 1). Management of coyotes in the DMA is left up to each municipality and/or county; thus, for any conflict that occurs, each municipality has its own procedures in place for how to manage it. The primary exception is when a coyote is aggressive toward a person and occasionally when a coyote is exhibiting extreme aggression with pets in the presence of humans, at which time Colorado Parks and Wildlife (CPW) will either carry out or contract out (USDA-Wildlife Services [WS] or private contractors) lethal removal of problem coyotes. Thus, we define problem individuals as those instances when CPW personnel deemed it necessary to remove coyotes in a particular area. Only 1 city within the DMA practiced proactive lethal removal of coyotes. Nonlethal management actions are also primarily reactive in the sense that such actions, like closing public spaces, posting signs, and/or other educational efforts, occur primarily with elevated conflict.

Evaluation of reactive lethal management: killing problem individuals

Our first objective was to evaluate the effectiveness of removing problem coyotes to reduce conflict and determine the impact of these removal efforts on the coyote population. To evaluate the effectiveness of removing problem coyotes, we used records of aggressive coyotes maintained by CPW that spanned from 2009–2014. These are records of human–coyote encounters (i.e., extreme conflict) in which a coyote was aggressive toward a person and resulted in a management action (lethal control) being carried out to remove problem coyotes. It is noteworthy that removal of problem individuals often involves guesswork about whether or not offending animals were killed. Thus, removal efforts often focus on areas where problems are occurring unless an individual can be easily identified (e.g., short tail, limp, or mangy coat). Importantly, these removals only account for control actions taken by government agencies; they do not account for control actions carried out by private individuals. However, due to strict trapping regulations in Colorado (i.e., private trappers are not allowed to use body gripping traps unless an exemption is issued, which has occurred once from 2007–2009 for a 21-km^2 area [<2% of the DMA]), the vast majority of control operations were carried out by government personnel.

In addition to listing the number of coyotes removed, this database also listed the location of the removals. The database contained no information about the sex or age of removed individuals. We used the location data to address the effectiveness of removal efforts on future conflict. We did this by calculating how much time elapsed (after a lethal control effort) until another conflict occurred that required lethal removal (i.e., recurrence). To carry out this analysis, we mapped point locations of each conflict event and then placed an 11.6-km^2 buffer around each point (i.e., average home-range size of resident coyotes in the DMA; Poessel et al. 2016). We then quantified the number of days that elapsed until another lethal removal occurred. We counted a recurrence any time 2 home-range buffers overlapped (see Figure 1). There are no published standards as to what constitutes an acceptable time period until another conflict; thus, we simply provide the data in descriptive form.

To determine the impact of lethal control actions on the coyote population in the DMA, we estimated the size of the coyote population in the DMA and then quantified the number of coyotes lethally controlled to estimate the percentage of coyotes annually removed from the population for conflict management. We estimated coyote population size during both winter (adults only) and summer (both adults and pups). We first calculated the area of the DMA where coyotes were most likely to reside. From the DMA polygon (Figure 1), we removed the most highly industrialized areas (e.g., downtown Denver) based on building density data from the Spatially Explicit Regional Growth Model (SERGoM v3; Theobald 2005) and then calculated the remaining area of the DMA. We then removed the area of the city practicing proactive lethal control of coyotes. Next, we divided the remaining area by the average home-range size of resident coyotes (Poessel et al. 2016) to determine the estimated number of coyote packs living within the DMA. We then estimated the average number of coyote adults and pups residing within a pack. We based the estimate of adults on our records and other urban coyote studies. Group size in Cape Cod, Massachusetts, USA ranged from 2–4 adults (Way et al. 2002), and pack size in Chicago, Illinois, USA ranged from 4–6 adults (Gehrt 2006, Gehrt and Riley 2010). We based the estimate of pups on monitoring of den sites we conducted during the 2013 pup-rearing season. We used both personal observations of dens and photographs from motion-activated trail cameras (RECONYX, Inc., Holmen, Wisconsin, USA) set up at den sites to count the number of pups at each den. We then averaged this pup count to estimate the mean number of pups in a pack. We used the mean number of adults to estimate the pack size for winter, and we used the mean number of adults and pups to estimate the pack size for summer. We then multiplied the estimated number of coyote packs by the mean number of adults and pups to determine the mean number of residents in both winter and summer. We multiplied the number of adult residents by 15% (based on Poessel et al. 2016 and previous studies) to represent the estimated number of transient coyotes, which we then added to the number of residents to produce estimates of the coyote population in both winter and summer. Because of high variability in the home-range sizes of resident coyotes and the number of pups in a pack, we further calculated 95% confidence intervals (CI) of these values and the estimated number of packs, pack size, number of residents and transients, and population size. We then quantified the number of coyotes removed annually using the CPW database described above, and we cross-checked these with WS records and verbal inquiries of specific events. We calculated the percent of coyotes removed on an annual basis by dividing the number removed by the population estimate calculated in the winter (i.e., low estimate) and summer (i.e., high estimate).

Evaluation of reactive nonlethal management: community hazing experiment

Bonnell and Breck (2017) define and justify the concept behind a type of hazing termed community-level hazing. The intent is that through education, urban citizens will become informed and emboldened to haze (primarily yelling, throwing objects, and/or aggressively approaching individuals) coyotes more frequently so that coyotes retain or gain more fear of people and thus minimize the development of problem individuals. This type of hazing is commonly promoted by animal activist groups, but there is very little research that evaluates whether such activities are effective. There are 2 critical aspects to this concept: changing the behavior of people and changing the behavior of coyotes. Here we provide more details of the study designed to evaluate community-level hazing impacts to coyote–human activity overlap.

Our objective for this experiment was to determine whether community-level hazing made coyotes less visible or active around people. We focused the experiment on sites where conflict had increased; thus, our efforts are best described as reactive nonlethal control. We employed a treatment and control design to determine if our education efforts were effective at changing coyote behavior. We selected 4 urban park and open space areas in Jefferson County and conducted our experiment from early February through early March 2014. Two sites were control areas (Belmar Park and Van Bibber Open Space; Figure 1) where citizens were only asked to report coyote sightings and interactions. Two sites were treatment areas (Crown Hill Park and Bear Creek Greenbelt; Figure 1) where, in addition to asking citizens to report coyote sightings, educational efforts were employed to encourage people to haze coyotes. Treatment sites were not randomly assigned because local governments requested that treatment sites be focused on areas where complaints about coyotes had increased. At 1 of the treatment sites (Crown Hill), it was clear that a problem individual had developed because many reports were filed prior to and during the study that an individual coyote was jumping out of the grass and acting aggressively toward pedestrians and their dogs.

At both treatment sites, we applied community-level hazing education/training techniques that could be deployed by wildlife and/or land managers in urban and suburban areas. The application lasted 3 weeks. Passive, non-personal hazing education signs were posted at major park access points and high-volume activity nodes at the treatment sites. These full-color, 61 × 91-cm, 2-sided sandwich board signs provided basic information about how to haze and encouraged park visitors to haze coyotes when observed. We augmented signs with social media, email blasts from land managers, and staffed volunteer education stations at major park access points. As part of the application, we created a "How to Haze a Coyote" educational video and posted it on YouTube (<https://www.youtube.com/watch?v=7MOnDIx71Q0>) with a QR code link to the video on all educational signs. Hazing efforts were further encouraged by site visits from staff, volunteers, and citizen scientists who could model proper hazing techniques for residents and park visitors (Worcester and Boelens 2007).

We used Bushnell 8.0 megapixel Trophy HD cameras (Bushnell Outdoor Products, Overland Park, Kansas, USA) to record activity of coyotes and make inference about coyote behavior. We placed 5 cameras at each of the 4 sites for a 3- to 4-week period. Three cameras were placed on main trails that were frequently traveled by people, and 2 cameras were placed on game trails that were likely to be formed primarily by wildlife and that offered less human traffic and generally more cover. No scent or attractant was used on any of the camera stations. We considered any human or coyote pictures with ≥10 min elapsed between photos to be independent observations. Because our cameras recorded the time a photo was taken of both people and coyotes, we were able to calculate the overlap in time of activity between humans and coyotes as the response variable to assess the impact of hazing on coyote avoidance of human activity areas. If our hazing treatment had an effect, then we hypothesized that activity overlap would be less in treatment areas, especially along main trails. To calculate the degree of overlap, we used the "overlapTrue" function in the "overlap" package (Meredith and Ridout 2013) in R (R Core Team 2015), which compares time series data generated from wildlife cameras and calculates an overlap coefficient that varies between 0 (no overlap) and 1 (perfect overlap). We estimated activity patterns of coyotes and people and quantified overlap in activity on main trails and game trails separately. We followed the recommendations of Meredith and Ridout (2013) for bandwidth selection, estimators for quantifying overlap, and number of bootstrap simulations to estimate CIs. We tested separately whether overlap between humans and coyotes differed between treatment and control sites on main trails and game trails.

Results

Coyote population size

We developed an estimate of the coyote population in the DMA by estimating the number of packs and average pack size. Our estimate was conservative because we first removed 27% of the DMA to account for highly industrialized areas where we assumed coyotes were unlikely to reside. We further

Table 2. List of coyote (*Canis latrans*) incidents that resulted in lethal removal of coyotes in the Denver Metropolitan Area, Colorado, USA, from 2009–2014. IDs of removals correspond to the numbers on Figure 1 to show the spatial location of removals. N/A indicates that no further incidents occurred within the buffer around the location of removal. Date indicates the month and year that the incident occurred, and # days is the number of days that passed before another incident occurred, or until the end of 2014 if no other incident occurred.

IDs of removals	First incident date (# days)	Second incident date (# days)	Third incident date (# days)	Fourth incident date (# days)
1	02/2009 (2,159)	N/A	N/A	N/A
2	05/2009 (2,070)	N/A	N/A	N/A
3	10/2009 (1,917)	N/A	N/A	N/A
4	11/2009 (1,886)	N/A	N/A	N/A
5	12/2009 (1,829)	N/A	N/A	N/A
6	01/2010 (1,825)	N/A	N/A	N/A
7	04/2010 (1,735)	N/A	N/A	N/A
8	09/2011 (1,217)	N/A	N/A	N/A
18	11/2013 (425)	N/A	N/A	N/A
19	01/2014 (364)	N/A	N/A	N/A
20	02/2014 (321)	N/A	N/A	N/A
27	06/2014 (213)	N/A	N/A	N/A
9,10	09/2011 (30)	10/2011 (1,187)	N/A	N/A
11,15	01/2012 (366)	01/2013 (729)	N/A	N/A
13,24	11/2012 (546)	05/2014 (244)	N/A	N/A
21,23	03/2014 (31)	04/2014 (274)	N/A	N/A
12,14,16	08/2012 (146)	01/2013 (489)	05/2014 (225)	N/A
17,22,25,26	01/2013 (424)	03/2014 (61)	05/2014 (111)	08/2014 (133)

Table 3. Number of pictures taken of coyotes (*Canis latrans*) and humans at the 4 study sites (T = treatment sites, C = control sites) within the Denver Metropolitan Area, Colorado, USA, 2014. M indicates main trails built for human travel, and G indicates game trails that are smaller secondary trails resulting from frequent travel by wildlife and occasional humans.

Site	Bear Creek (T)		Crown Hill (T)		Van Bibber (C)		Belmar (C)		Total
	M	S	M	S	M	S	M	S	
# Coyote pictures	78	23	45	23	73	16	20	11	289
# Human pictures	10,319	382	23,630	1,257	5,651	49	9,361	447	51,096

removed 21 km^2 corresponding to the area of the city that practiced proactive lethal removal of coyotes, resulting in a remaining area of 1,268 km^2. The mean home-range size for resident coyotes was 11.6 km^2 (SE = 2.5 km^2; 95% CI = 6.7–16.5 km^2; Poessel et al. 2016). Hence, the estimated number of coyote packs was 109 (95% CI = 77–189). We estimated an average of 4 adults (range = 2–6) and an average of 4.4 pups (SE = 0.6; 95% CI = 3–6) in a pack, resulting in a total of 8.4 coyotes (95% CI = 5–12) in a pack. We then estimated 436 residents in winter (adults only; 95% CI = 154–1,134) and 916 residents in summer (pups and adults; 95% CI = 385–2,268). After adding 15% of adult residents to represent transients (65; 95% CI = 23–170), our final estimate of coyote population size was 501 coyotes in winter (95% CI = 177–1,304) and 981 coyotes in summer (95% CI = 408–2,438).

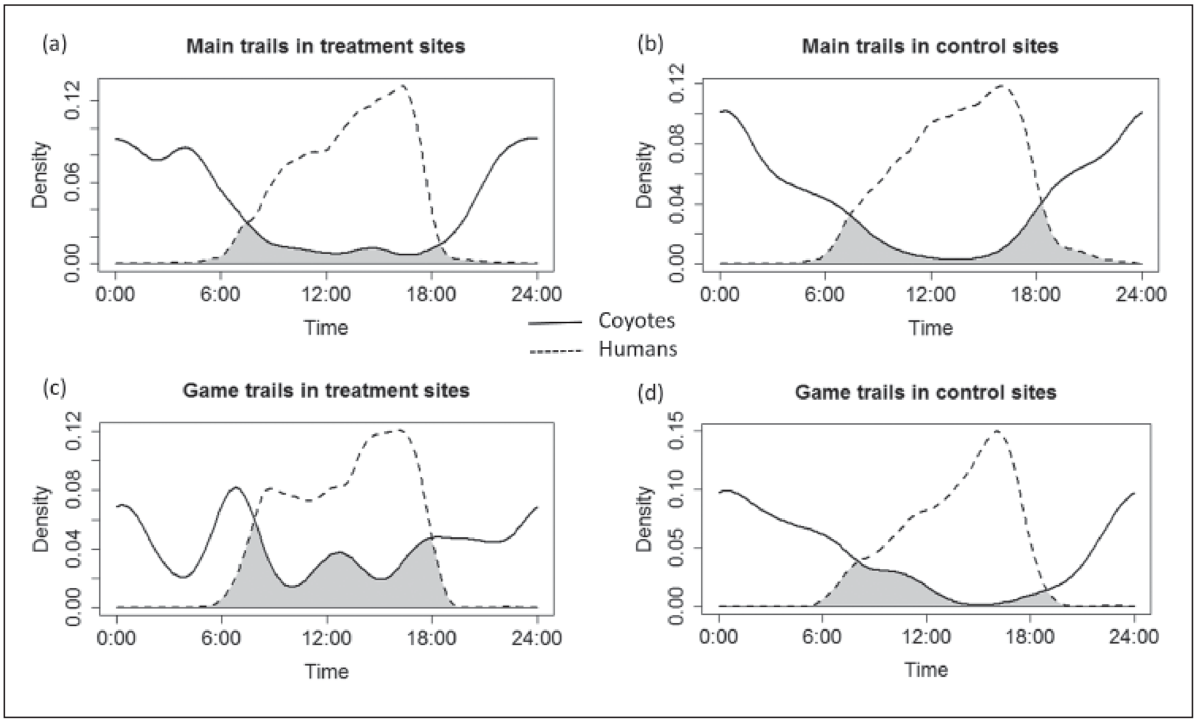

Figure 2. Results from the hazing study showing overlap in activity patterns (grey shading) between humans (dashed line) and coyotes (*Canis latrans*; solid line) within the Denver Metropolitan Area, Colorado, USA, 2014. Panels (a) and (b) depict activity on main trails in treatment and control sites, respectively. Panels (c) and (d) depict activity on game trails in treatment and control sites, respectively.

Conflict recurrence and impact of removing problem coyotes

From 2009–2014, a total of 56 coyotes were lethally removed during 27 events for causing severe conflict (i.e., aggressiveness toward people). The average number of incidents resulting in removal of coyotes was 4.5 per year, the average number of coyotes removed per event was 2.1 (range 1–11), and the average number of coyotes removed per year was 9.3. The estimated percentage of coyotes removed per year from the population for problem behavior was 1.8% (using the winter population estimate) and 1.0% (using the summer population estimate). There were 6 areas where the buffer around a coyote removal overlapped with another buffer (Figure 1, Table 2). One area had 4 removal events overlap, 1 area had 3 removal events overlap, and 4 areas had 2 removal events overlap. For the 9 recurrence events, the mean time until recurrence of a severe conflict was 245 days (range 30–546), and for the 18 events without recurrence, the mean time since the conflict event was 1,042 days (range 133–2,159); we note that this is a conservative estimate because we stopped counting days at the end of 2014.

Nonlethal hazing experiment for altering coyote behavior

We recorded >50,000 independent sightings of people and coyotes, with the vast majority of sightings being people and with most human activity recorded on the main trails vs. game trails (Table 3). Overall, twice as many photos of coyotes were recorded on main trails (18.0 pictures/camera) vs. game trails (9.1 pictures/camera). On main trails and game trails in both treatment and control sites, human activity began growing at approximately 0600 hours and peaked at approximately 1700 hours (Figure 2). Coyote activity was primarily nocturnal with peak activity occurring at 2400 hours for all but game trails in treatment sites (Figure 2a,b,d). At these trails (Figure 2c), coyote activity fluctuated more dramatically than activity at the other trail/site combinations. Activity overlap (grey shaded areas in Figure 2a–d) between people and coyotes occurred primarily during mornings and evenings (Figure 2). We found the coefficient of overlap between humans and coyotes was lower on treatment vs. control sites on main trails (matching our prediction) but higher on treatment vs. control sites on game

Table 4. Estimated coefficient of overlap (with 95% CIs) between humans and coyotes (*Canis latrans*) in urban open space areas. Main trails were primary paths built in parks, and game trails were smaller secondary paths in the study sites. We employed community-based hazing efforts in treatment areas, and no hazing was employed in control areas.

Main trails		Game trails	
Treatment	Control	Treatment	Control
0.18	0.24	0.41	0.23
(0.10–0.23)	(0.15–0.27)	(0.28–0.46)	(0.09–0.33)

trails (contradicting our prediction; Table 4). Importantly, confidence intervals of treatment and control sites on main trails overlapped considerably (Table 4), indicating a weak relationship between groups. The confidence intervals between treatment and control sites barely overlapped for the game trail comparison, indicating the greater overlap of activity on treatment sites was perhaps a more robust biological difference.

Discussion

The primary management challenge associated with urban coyotes is the development of problem individuals that show extreme forms of aggression toward people and their pets. Our results support the idea that targeted lethal removal of problem individuals can reduce conflict, but do not support the idea that promoting the public to haze coyotes will solve problems associated with overly aggressive/bold individuals that have become problem coyotes. However, we qualify findings from the hazing study, particularly given limitations of the study design and difficulties in measuring an adequate behavioral response from coyotes, as discussed below.

The decision to lethally remove problem coyotes can be controversial, with unsupported claims about the effectiveness and impact of removal efforts on the coyote population. One common claim is that lethal removal will not stop the problem and that conflict will recur and require continual lethal control efforts. This statement is accurate in that occasional removal of problem coyotes will likely be continually necessary in urban areas with coyotes. However, such statements would be more meaningful by specifying the recurrence duration so managers can make more informed decisions about the costs and benefits of such actions. We quantified conflict recurrence with coyotes in the DMA and found that there was recurrence at 33% of locations where lethal removal occurred. Where there was recurrence, on average it was about 8 months between events and, in the 67% of locations with no recurrence, an average of nearly 3 years passed since the removal occurred. However, this estimate is conservative because we stopped counting days at the end of 2014. Our results indicate that extreme cases of urban coyote conflict are isolated events (4.5 per year) and that reactive removal of problem individuals usually, but not always, stopped subsequent conflict for prolonged periods (several years). There were a few exceptions when extreme conflict occurred in close proximity and in quick succession (e.g., locations 9, 10 or 21, 23 on Figure 1; Table 2). It is possible in these cases that the original removal effort did not get the right individual(s) and thus required further work; targeting the correct coyote in reactive removal efforts is among the more difficult tasks, and below we identify key components to increasing success of this endeavor (Sacks et al. 1999). We acknowledge that there are other ways to calculate recurrence that would change recurrence patterns either positively or negatively, but it is relevant that our methodology is based on repeatable biological measures (e.g., recorded conflict removals and home range size of coyotes) and offers a means of objectively quantifying recurrence of conflict. Such a measure could be useful for comparing conflict patterns across cities or across time.

Another claim opposing reactive lethal control is that such actions will have a negative impact on the coyote population. Our results indicate that reactive lethal control annually removed approximately 1–2% of the DMA coyote population. This impact to the coyote population is trivial from a population perspective, given that research suggests that annual removal of approximately 50–70% of the coyote population is necessary to drive down the population density (Connolly and Longhurst 1975, Gese 2005). Thus, the notion that reactive removal of problem individuals will negatively impact the coyote population has no merit at the levels of removal we documented in the DMA. Finally, there are claims that lethally removing coyotes causes an increase in pup production (e.g., Coyotes, Wolves, and Cougars, <http://coyotes-wolves-cougars.blogspot.com/2016/08/project-coyote-director-camilla-fox.html>, accessed August 11, 2016), but this claim has only been verified when removal efforts take 50–60% of the coyote population (Gese 2005). There is no population modeling or empirical evidence to support the notion that removal of a few problem individuals will cause an increase in pup production.

Most importantly, the removal of problem individuals is not meant to be an effort to impact the population but rather an effort to impact the behavior of coyotes. At a minimum, removing problem individuals eliminates those few coyotes that are exhibiting bad behavior (i.e., boldness or aggressiveness toward people) but may also act as a selective force that reduces the potential for cultural and/or genetic transfer of behavior to future generations of coyotes. We know very little about how problem behavior is acquired in coyotes, but it is logical to hypothesize that leaving problem individuals on the landscape could enhance the transfer of these behavioral traits to other individuals. Such transfer of problem behavior has been investigated in black bears (Breck et al. 2008, Mazur and Seher 2008, Hopkins 2013) and likely occurs in many carnivore species.

We caution that our results do not imply that more liberal lethal control (i.e., >1–2%) will result in even less conflict. Most conflict in urban areas is associated with aggressiveness toward dogs, but this aggression toward other canids is likely a deeply engrained trait present in all coyotes. We believe targeted removal should focus on cases when aggression is directed at people or extreme cases of pet aggression (e.g., attacking dogs on leashes).

As an alternative to lethal control, it is commonly recommended that people use hazing to reduce conflict with urban coyotes (e.g., Humane Society of the United States, <http://www.humanesociety.org/assets/pdfs/wild_neighbors/coyote_hazing.pdf>, accessed August 11, 2016). It is noteworthy that no scientific research has been conducted on the effectiveness of hazing for reducing urban coyote conflict. White and Delaup (2012) strongly promote hazing, but their recommendations are not founded on science (e.g., their paper does not include any methods or data to properly evaluate their work). Results from our experiment indicated that hazing had no detectable effect on influencing coyotes to avoid human-rich areas. Specifically, we found that the activity overlap between people and coyotes was essentially equivalent (main trails) or greater (game trails) in treatment sites than control sites, which is counter to predictions of our hazing treatment effect. These results provide evidence that encouraging the community to haze does not reduce long-term exposure, possibly because either the hazing does not affect coyote behavior long term or because the community does not properly implement hazing.

However, we advise caution in interpreting our hazing experiment results, as we believe there were some important limitations. First, we initially tried to record a more direct form of interaction between humans and coyotes by having the public report interactions during the experiment. Based on surveys of the public, only 10–23% of people that saw coyotes at our study sites actually reported their sighting, and only 23% of people that saw a coyote reported that they actively hazed the coyote (Breck, unpublished data); thus, the treatment effect may not have been strong enough to influence coyote behavior. Furthermore, we saw a decline in public reports of coyotes over the 3-week period of our hazing study (Breck, unpublished data), indicating that there was a strong reporting bias associated with public reports from the hazing study. Thus, we relied on an indirect measure of interaction (i.e., calculation of activity overlap between people and coyotes), which offered a robust biological measure but is a questionable response variable for understanding how coyotes respond to humans. Given that open spaces are so attractive for both people and coyotes (Poessel et al. 2016; Table 2), it should be expected that there will be interaction. It is critical to know how coyotes respond to people when interactions occur. Bonnell and Breck (2017) demonstrated that hazing usually resulted in a short-term flight response by coyotes, but relating these short-term responses to longer-term behavioral avoidance of people is a very difficult response variable to measure accurately in our experience.

Second, there may have been important differences between the treatment and control areas that inherently biased the measure of overlap between humans and coyotes. More people used the 2 treatment sites than the control sites (~35,000 vs. ~15,000), which may have biased our results by influencing coyotes to be more accustomed to people. More importantly, we assigned our treatments to areas known to have increased complaints about coyotes (done at the request of cooperating entities); thus, the treatment population may have been different from the control. This was evident at 1 of our hazing treatment sites (Crown Hill), where an aggressive and exceptionally bold coyote would hide alongside main trails and confront and occasionally attack dogs on leashes. This individual likely dominated sightings and possibly the number of coyote pictures taken because it spent a great deal of time on main trails. Despite efforts from the public and personnel from the study to haze this individual, we saw no long-term change in aggressive behavior, and this individual was lethally removed about 1 month after the hazing experiment concluded.

We provide details of this event because it helps highlight a critical point; namely, we believe that hazing efforts should be conducted proactively on all coyotes and not reactively on problem individuals. Hazing problem individuals can have short-term benefits that enable people to escape dangerous situations (see Bonnell and Breck 2017), but there is little evidence showing hazing will change problem behavior over the long term. This conclusion is supported by a similar anecdote that occurred in Boulder, Colorado, USA, a city bordering the DMA. In this case, problem coyotes were documented repeatedly chasing and biting people along a bike trail. Personnel attempted a 28-day intensive hazing program (similar to our experiment) in January 2013 to train these problem coyotes, which reportedly had short-term benefits, although problems continued in the area after the hazing trial stopped, prompting removal of 2 coyotes (Daily Camera, <http://www.dailycamera.com/news/boulder/ci_24721335/boulder-not-planning-more-coyote-hazing-year-after>, accessed August 11, 2016).

We emphasize that nonlethal methods should be used to prevent the development of problem individuals, not to correct the behavior of individuals that have already developed the behavior. Although our study of hazing was flawed in many regards, we believe it is important to publish these results to help guide future efforts. There is a great need for research on the effectiveness of nonlethal methods, but the questions are exceptionally challenging to pursue, and we hope lessons outlined here will be valuable when designing future studies.

Despite the lack of meaningful results supporting the idea of hazing having positive long-term impacts on coyotes avoiding human activity areas, hazing does have important short-term impacts that can help citizens get out of potentially dangerous situations with coyotes (Bonnell and Breck 2017). Furthermore, engaging residents in community-level, nonlethal management of coyotes has positive, empowering impacts with measurable changes in knowledge and attitudes (Bonnell and Breck 2017). Unfortunately, because of the nature of urban coyote conflict, managers and the public often tend to ignore coyotes until an individual begins to show extreme forms of aggressive behavior. It is only after a problem individual develops that these techniques are implemented, and we believe this is a grave mistake that dooms the effectiveness of nonlethal methods. Specifically, we believe it is critical to have strong and meaningful enforcement to reduce purposeful feeding of coyotes and have the public actively engaged in scaring and hazing coyotes whenever there is opportunity, similar to the recommendations of Bonnell and Breck (2017) and Poessel et al. (2017). However, this opinion is dependent on having a management plan and resources in place that allows for proactive work. Lack of funding can be a major impediment for most government entities because the benefit of education and carrying out campaigns to have a more engaged public are long-term efforts.

Management implications

Given the reactionary nature of management, the long timeframe required for educational efforts, and the poor efficacy of hazing problem coyotes, we believe that the removal of problem individuals is an important management option to consider for municipalities dealing with human–coyote conflict. To avoid excessive take of non-problem individuals requires the ability to target the correct individual(s) and efficiently and humanely remove them. In our experience, removal efforts benefit when personnel with good knowledge of local coyote activity is married with trained professionals with experience in safe and humane removal techniques in urban environments. Thus, we encourage cities to allow personnel to observe and become familiar with the coyotes in their city so they can provide details of coyote activity patterns, especially in areas experiencing problems. We also encourage cities to develop relationships with managers (private, state, or federal) that are skilled in humane removal of coyotes. We further encourage cities to develop proactive educational efforts focused on prevention of conflict, such as the program developed by M. Bonnell in the DMA (see Bonnell and Breck 2017 for details). Some nonprofit organizations are actively engaged in developing such programs (e.g., Humane Society of the United States and Project Coyote), and we recommend partnering with such entities with the caveat that lethal removal of problem individuals remains a viable option in the management plan. Finally, we believe that further research on how problem individuals develop and on the effectiveness of nonlethal methodologies are important priorities.

Acknowledgments

Many entities helped with this research including personnel from the City and County of Broomfield, Jefferson County, and the City of Lakewood. Specifically we thank J. Brinker, P. Dunlaevy, F. Quarterone, D. Lewis, E. Hunholz, J. Kougher, S. Koyle, B. Massey, J. Mckee, E. Mock, R. Much, E. Nilsen, K. Pritz, R. Raker, R. Sedbrook, D. Sprafke, and C. Zinanti for assistance and logistical support. Funding was provided by the USDA-Wildlife Services National Wildlife Research Center, Colorado Parks and Wildlife, USDA-Wildlife Services, Ecology Center at Utah State University, and City and County of Broomfield. We thank 3 anonymous reviewers that helped improve the article.

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