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ARTICLE

Methods, Tools, and Technologies

Proactive use of intensive aversive conditioning increases probability of retreat by coyotes

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Abstract

Coyotes (*Canis latrans*) are showing increasingly bold behaviors toward people and their pets throughout North America. Bold behavior by wildlife might be reduced by hazing and aversive conditioning, which is recommended in many management plans for coyotes, but with little information about how it is to be conducted, and few studies have tested this approach. We conducted an online search for coyote management plans across North America to review techniques and recommendations related to the implementation of hazing or aversive conditioning and reported on the implementation of a high-intensity aversive conditioning program in Calgary, Alberta, Canada. Almost all the management plans recommended hazing coyotes, most often by using a combination of noises, lights, and movements, but only 20% of 71 plans recommended high-intensity techniques like those used by the contractors in Calgary. Contractors there searched for coyotes in 72 public park areas where members of the public had submitted reports to a civic call center for bold coyotes, attended sites on 1917 occasions, observed coyotes on 765 occasions, and reported coyote treatments and responses on 734 occasions. The probability of coyote retreats increased by 29%–37% with each additional previous aversive conditioning event at the site and doubled with the presence of dogs and with the application of projected chalk balls prior to the event being investigated, suggesting coyotes learned to avoid contractors. During engagements with contractors, coyote retreat probability declined by 21%–25% with each additional day since the last aversive conditioning engagement, and by 97.2%–97.6% with the presence of dogs and when shots were fired from a paintball gun, presumably because these tools were used only on the boldest coyotes. We found no effect of the presence or past number of aversive conditioning events on the number of coyote reports per week by the public. Although such high-intensity aversive conditioning is rarely recommended in management plans, our results suggest that its repeated application can reduce coyote boldness over time, but coyotes may not generalize this response to other people owing to visual cues (e.g., high-visibility vests, consistent vehicles) associated with contractors.

KEYWORDS
Alberta, aversive conditioning, *Canis latrans*, coexistence planning, coyote, hazing, human–wildlife conflict

INTRODUCTION

Since the late 1990s, coyotes (*Canis latrans*) in urban areas have shown increasingly bold behaviors toward people and their pets such as approaching, stalking, pursuing, or attacking pets or people (Baker & Timm, 2016; Lukasik & Alexander, 2011; Poessel et al., 2013; Timm et al., 2004; White & Gehrt, 2009). More recently, unusual spikes in the frequency of coyote attacks on people have been reported in several cities, including Chicago (Illinois; Andrew & Alonso, 2020), Calgary (Alberta; Kaufmann, 2021), the San Francisco Bay Area (California; Diaz, 2021), Vancouver (British Columbia; Griffin, 2022), and Burlington (Ontario; The Canadian Press, 2022). Although such incidents remain rare, urban residents have long expressed concerns about the presence of coyotes in their neighborhoods (Siemer et al., 2014; Webber, 1997; White & Gehrt, 2009) and that concern is increasing (Drake et al., 2020; Farr et al., 2023).

Municipalities across North America have responded to the increased prevalence of urban coyotes and associated conflicts with management plans that address human–coyote coexistence (Appendix S1: Table S1). Typical goals of these plans are to increase communication among stakeholders and wildlife professionals (Alexander, 2013; Marchini et al., 2019), identify the types of actions that should be used to address human–coyote conflicts, and provide direction for implementing those actions (Schwartz et al., 2018). Many of the plans are based on a template provided by The Humane Society of the United States (2019), which recommends targeted lethal management of animals that bite people, opposes the use of translocations, and encourages the use of low-intensity hazing (Lesmerises et al., 2018). Targeted lethal removal of individual problem coyotes is effective in reducing conflict with people (Breck et al., 2017), but lethal management of coyotes is logistically difficult, time-consuming, expensive, and increasingly opposed by the public (Berger, 2006; McCullough et al., 1997; Sponarski et al., 2018; Worcester & Boelens, 2007; Yashphe & Kubotera, 2017). Although the translocation of problem animals may be perceived by the public as more humane than targeted lethal management (e.g., Dubois & Harshaw, 2013), the survival rates of translocated coyotes is very low (Learn, 2021), which is typical of other carnivores (Blanchard & Knight, 1995; Boast et al., 2016; Bradley et al., 2005; Linnell et al., 1997). The limitations of lethal management and translocations underscore the need for hazing as a more proactive, nonlethal method to address human–coyote conflicts in urban areas.

Hazing and aversive conditioning are recommended by many authors as humane, nonlethal tools to manage bold urban coyotes (Bonnell & Breck, 2017; Sampson & Van Patter, 2020; The Humane Society of the United States, 2019; White & Delaup, 2012). Although these terms are often used interchangeably, hazing refers to the reactive application of negative stimuli to immediately change an undesirable behavior (Schirokauer & Boyd, 1998), whereas aversive conditioning is a learning process in which negative stimuli are repeatedly and consistently applied to reduce the frequency of an unwanted behavior over longer periods of time (Domjan, 2014; Hopkins et al., 2010). Aversive conditioning has been used to manage a variety of wildlife species, including elk (*Cervus canadensis*; Found et al., 2018; Kloppers et al., 2005), black bears (*Ursus americanus*; Beckmann et al., 2004; Homstol, 2011; Mazur, 2010), wolves (*Canis lupus*; Rossler et al., 2012; Schultz et al., 2005), and African lions (*Panthera leo*; Petracca et al., 2019).

Aversive conditioning or hazing might be used by wildlife professionals and members of the public to address bold behavior by urban coyotes, and these approaches are variously described in several online municipal coyote management plans. A French language review of these online plans (Lesmerises et al., 2018) suggests that they vary in the types, intensity, and implementation sources recommended for aversive conditioning, but there is no authority with which to evaluate these differences. Furthermore, few studies have tested the efficacy of hazing or aversive conditioning, which some authors dispute (Alexander, 2022; Brady, 2016; Sampson & Van Patter, 2020). Low-intensity aversive conditioning conducted by volunteer community scientists who were instructed to shout, use noise makers, make themselves appear big, and approach the animal has produced an immediate fleeing response in urban coyotes (Bonnell & Breck, 2017). However, this method did not cause coyotes to avoid areas frequented by people, and a companion study suggested that it should be applied proactively on all coyotes, rather than reactively only on problem individuals (Breck et al., 2017). A study conducted on captive coyotes that experienced similar aversive conditioning techniques found that an increasing number of hazing events led to a decrease in the number of approaches by coyotes toward people, providing evidence of a learned response, but with substantial variation among individuals (Young et al., 2019).

The efficacy of applying aversive conditioning to coyotes and other wildlife species might be increased by employing the principles of effective punishment developed in studies on lab animals and people that are summarized in many introductory textbooks on learning and conditioning (e.g., Domjan, 2014) and increasingly apparent in studies of wildlife (e.g., Evans Ogden, 2021; Found & St. Clair, 2019). These principles assert that the aversive stimuli should be immediate (e.g., Andelt et al., 1999), consistently applied when the undesired behavior occurs (e.g., Petracca et al., 2019), and not signaled by preliminary cues, such as particular trucks, uniforms, and locations (Homstol, 2011; Kloppers et al., 2005). The aversive stimulus should associate sounds with pain or taste with nausea, but not sound with nausea or taste with pain (i.e., evolutionarily relevance; Conover, 2002; Evans Ogden, 2021; Garcia et al., 1974; Homstol, 2011), and have high initial intensity (e.g., Homstol, 2011) to prevent the habituation that might result from a gradual increase in the intensity of the stimuli (Domjan, 2014) and exacerbate associated human–wildlife conflict.

In this study, we review coyote management plans across North America and report on the implementation of a high-intensity aversive conditioning program conducted in Calgary, Alberta, Canada. More specifically, we (1) identify the most common management techniques recommended to address bold behavior by coyotes in coyote management plans and summarize how hazing or aversive conditioning were to be implemented in those plans, and (2) evaluate the effectiveness of Calgary's program via coyote behavior as assessed by wildlife professionals and changes in public reporting of coyotes to a civic call center. We also recommend management strategies that are likely to maximize the efficacy of aversive conditioning as a proactive tool to promote human–coyote coexistence in urban areas.

METHODS

Study area

We evaluated the responses of coyotes to an aversive conditioning program conducted in the City of Calgary (825.3 km^2), located in southwestern Alberta in the foothills of the Canadian Rocky Mountains (Government of Canada, 2017). Calgary has an elevation of 1060 m above sea level (Liccioli et al., 2012), is characterized by mean temperatures ranging from −7.1°C in the winter to 16.5°C in the summer (Environment and Climate Change Canada, 2013), and had a human population of approximately 1.4 million people when the study began (Government of Canada, 2017). The municipal area contains over 80 km^2 of parkland and natural areas including Nose Hill Park, one of the largest municipal parks in North America (The City of Calgary and Local Action for Biodiversity Programme, 2014). Many city parks border riparian habitats along the Bow and Elbow Rivers. Native habitats in the city include forests, riparian tall shrublands, upland tall and low shrublands, grasslands, streams, and wetlands (The City of Calgary Parks, 2015). Seminatural habitats include manicured green spaces, gardens, agricultural areas, storm ponds, and built habitats. Both native and seminatural habitats present within the city are widely used by coyotes and other wildlife.

Coyote management plan review

In June 2021, we conducted an exhaustive online search of coyote management plans. Many online search engines were used including the Web of Science and Scopus, but Google provided the most comprehensive results for this query. Our initial search terms (in English and French) were "urban coyote management plan," "coyote management plan," "coyote coexistence plan," "coyote response strategy," "coyote protocol," "coyote hazing," "coyote aversive conditioning," and "plan de gestion coyote." Search terms were developed using Pearl growing, a systematic review strategy whereby documents of interest are used as "pearls" to identify keywords and index names (Schlosser et al., 2006). We then applied the keywords and index names to the search terms to identify other sources until the material searched became less relevant (Appendix S1: Table S1; Papaioannou et al., 2009). We did not restrict our search in time.

We identified the management techniques that were addressed in each management plan. When hazing was recommended, we characterized this technique by the types of tools suggested and classified these tools based on their intensity level (i.e., low, moderate, high; Homstol, 2011; Mazur, 2010). We also determined and characterized how the plans were to be implemented.

Aversive conditioning procedures

In response to increasing human–coyote conflicts (Lukasik & Alexander, 2011), the City of Calgary produced a coyote management plan and response guide to support human–coyote coexistence (The City of Calgary, 2018). The guide included the implementation of a high-intensity aversive conditioning program to be delivered by contracted wildlife professionals (hereafter contractors). At the same time, the City broadened its civic reporting system to include coyote observations and conflicts. Civic employees collated public reports of bold coyote activity and shared them with contractors who responded to them by patrolling associated parks where they attempted to engage coyotes with trained dogs and, when appropriate, used paintball guns to shoot chalk balls toward (and occasionally at) coyotes. The wildlife professionals measured and reported their own actions as well as the responses of coyotes to the aversive conditioning treatments.

Aversive conditioning was conducted in the City of Calgary by contractors and their trained dogs between September 25, 2018, and July 17, 2021. Contractors surveyed areas with reports of bold coyotes by vehicle and on foot to record whether or not coyotes were found and whether it was possible to safely engage with the coyotes to perform the aversive conditioning actions; all actions were coded on an ordinal scale (Table 1). Foot patrols usually included working dogs. Aversive conditioning actions included flushing coyotes from hiding cover with a dog and firing chalk balls from paintball guns at targets that were distant from, near to, or occasionally directly at coyotes (Table 1). If aversive conditioning was initiated, it continued until the coyote(s) left the area. Aversive conditioning was only conducted on city-owned land, including municipal parks, and was never conducted on young pups or with a goal to injure coyotes. Public safety was maintained during the aversive conditioning process by avoiding crowded areas and the use of conditioning near people. The contractors and their dogs wore high-visibility vests so that they could be identified and recognized by members of the public.

Analysis of aversive conditioning in Calgary

Contractors described the responses of coyotes to their actions on a five-point ordinal scale that ranged from leaving the area immediately without looking back (1) to physical attacks by the coyote on a dog or person (5; Table 2). Contractors also recorded the location and date of each conditioning event and, when possible, the number and sex of the animals being conditioned. We assigned aversive conditioning events to seasons relevant to coyote ecology: breeding season (January 1–April 30), pup-rearing season (May 1–August 31), and dispersal season (September 1–December 31; Morey et al., 2007).

Public reports of coyote sightings and encounters in the City of Calgary were collected from the City's

TABLE 1 Aversive conditioning actions ($n = 1917$ interventions, 765 aversive conditioning events) performed by private contractors between September 2018 and July 2021 in the City of Calgary, Alberta.

Aversive conditioning actions performed	Ordinal scale value	Aversive conditioning events		Dogs were used: Yes (1)/no (0)	Shots were fired: Yes (1)/no (0)
		No.	Percentage		
No aversive conditioning actions (no coyote seen or aversive conditioning could not be conducted due to the location of the coyote).	0	1152	60	0	0
Dogs were used. No shots were fired.	1	379	20	1	0
Dogs were not used. Distant shots were fired. Balls did not hit close to the coyote.	2	82	4.3	0	1
Dogs were not used. Shots were fired near the coyote. The coyote did not come into contact with a chalk ball.	3	55	2.9	0	1
Dogs were used. Shots were fired. The coyote did not come into contact with a chalk ball.	4	183	9.5	1	1
Dogs were not used. Shots were fired. The coyote came into contact with a chalk ball.	5	11	0.6	0	1
Dogs were used. Shots were fired. The coyote came into contact with a chalk ball.	6	53	2.8	1	1
Misclassified treatments	"4–5"	2	0.1	N/A	N/A

municipal monitoring database between May 2, 2018, and July 21, 2021. The data were obtained through private communications with the contractors in collaboration with the City of Calgary. When full reports were available, they were coded based on the encounter characteristics as described in the City of Calgary's Coyote Conflict Response Guide on an ordinal scale ranging from observation of coyote sign (e.g., scat) and coyotes to incidents involving conflict between coyotes and people or their pets (Table 3; The City of Calgary, 2018). Reports also included the location and time of the coyote observation. We included only those reports that described coyote activity, and excluded duplicate reports, reports for which no date was provided, and reports originating from parks where no aversive conditioning was conducted. We assigned coyote reports to seasons relevant to coyote

TABLE 2 Response of coyotes to aversive conditioning actions ($n = 734$ aversive conditioning events) performed and recorded by private contractors between September 2018 and July 2021 in the City of Calgary, Alberta.

		Aversive conditioning events	
Response of coyotes to aversive conditioning	**Ordinal scale value**	**No.**	**Percentage**
Coyotes left immediately and did not stop to look	1	353	48
Coyote delayed leaving for a few moments but did not let the contractors get close. Eventually took off	2	254	35
Coyote delayed leaving, required multiple pushes, and did not vacate right away	3	107	15
Coyote challenged the dog and was not leaving, requiring close quarter aversive conditioning	4	17	2.3
Coyote physically attacked the dog or handler resulting in either a close call or an actual bite	5	3	0.4

TABLE 3 Classification code of reports of coyote activity ($n = 826$ coyote reports) submitted by members of the public to the City of Calgary's 311 reporting database between May 2018 and July 2021 for the 72 parks or park areas subjected to aversive conditioning.

				Reports	
Observation or conflict	**Nature of coyote report**	**Ordinal scale value**	**Definition**	**No.**	**Percentage**
Observation	Sign	1	The act of noticing or taking note of tracks, scat, or vocalizations that indicate the activity of coyote(s) in an area.	4	0.5
	Sighting	2	A visual observation of a coyote(s).	313	38
	Encounter	3	An interaction between a human and a coyote that is without incident.	186	23
Conflict	Incident—dog	4	A conflict between a dog and a coyote where a coyote exhibited behavior creating an uncomfortable situation for the human, which includes baring teeth, growling, snarling, stalking a dog or crouching as if to attack a dog, or a dog is attacked without injury to the dog.	79	9.6
	Incident—human	5	A conflict between a human and a coyote where a coyote exhibited behavior creating an uncomfortable situation for the human, which includes baring teeth, growling, snarling, stalking a human, or crouching as if to attack a human.	173	21
	Pet attack	6	Domestic pet is attacked by a coyote (either injured or killed).	58	7.0
	Human attack	7	A conflict that involves physical contact between a coyote and a human; a human is injured or killed by a coyote.	13	1.6

ecology in the same way as described for the aversive conditioning events.

To examine the spatial and temporal distribution of aversive conditioning events, coyote responses to wildlife professionals, and reports to the civic 311 system, we tallied each type of information in each ordinal category by park (or park area within a large park or multiple small parks within a neighborhood) and coyote season (Appendix S2: Table S1). We used one-way ANOVA to compare the number and types of reports and aversive conditioning events among parks and the three coyote seasons (breeding, denning, and dispersal).

To maximize statistical power in our analyses of the number and type of coyote interactions described by contractors and 311 reports, we converted the ordinal scales for our three main response variables to binary categories. For coyote presence as assessed by contractors, we separated instances where no coyotes were found (Category 0) from instances where coyotes were observed and aversive conditioning was conducted (Categories 1–6; Table 1). Similarly, for coyote responses to contractors, we separated responses indicative of retreat by coyotes (Categories 1 and 2) from those associated with resistance (Categories 3–5; Table 2). Finally, for public 311 reports, we separated reports associated with observation (Categories 1–3) from those associated with conflict (Categories 4–7; Table 3). As explanatory variables, we coded each event to identify whether a dog was used and whether or not the contractors fired chalk balls in close proximity to or directly at the coyote (coded as follows: 1, dogs were used, shots were not fired; 2, dogs were not used, shots were fired; 3, dogs were used, shots were fired; Table 1). Additional explanatory variables included the number of days since the last aversive conditioning engagement and a count of the number of aversive conditioning events for each park or park area in the one week (7 days, presence model) or eight weeks (56 days, all other models) prior to or during the day of the report. We chose these time periods after testing durations that ranged from 1 to 8 weeks with separate logistic regression models and proceeding with the time period that resulted in the lowest Akaike information criterion corrected for small sample size (ΔAIC_c) (Burnham & Anderson, 2002). We also tallied the number of 311 reports of coyote activity in a park in the four weeks (7 days, presence model) or eight weeks (56 days, all other models) prior to the report and included as covariates the season relevant to coyote ecology (breeding, pup-rearing, dispersal) and the year of the study (coded as 1–4 beginning in 2018).

We used logistic regressions to model each of the binary response variables associated with coyote responses to wildlife professionals (presence or absence and retreat or resist) and with 311 reports (conflict or observation) with potential fixed explanatory variables that included coyote season, year, the aversive conditioning treatment, the number of days since the last aversive conditioning engagement, and variables related to recent aversive conditioning events and recent coyote reports. We investigated the number of aversive conditioning engagements by contractors and the number of reports of coyote activity made to 311 (tallied separately for each park or park area) in the weeks prior to the event. The continuous explanatory variables were scaled. For the model predicting the type of coyote report (conflict or observation) made to 311, we only considered the coyote reports submitted following the first aversive conditioning event in each park. We included park or park area in these models as a random effect to accommodate repeated use of locations. Models were built using the glmer function of the "lme4" package (Bates et al., 2014), with a binomial family link (De Boeck & Partchev, 2012; Lee & Grimm, 2018). We evaluated models based on their AIC_c score using the dredge function in the "MuMIn" package (Bartoń, 2022); we identified top models as those with a difference in their $\Delta AIC_c < 2$ (Stephens et al., 2006; Symonds & Moussalli, 2011; Tredennick et al., 2021). We identified uninformative parameters as those whose 85% CIs included zero, increasing the compatibility between the model selection (via ΔAIC_c) and the parameter evaluation processes (via CIs; Arnold, 2010). We excluded models that contained at least one of these uninformative parameters if the other parameters were present in another model that we retained (Arnold, 2010). Spearman's correlation coefficients among predictor variables were <0.5, limiting the effects of multicollinearity (Dormann et al., 2013). We determined the proportion of variance explained by our best models via Nakagawa R^2 using the r.squaredGLMM function of the "MuMIn" package (Bartoń, 2022), which provides marginal and conditional r^2 values and is adapted to generalized linear mixed-effects models (GLMMs) (Nakagawa et al., 2017; Sugden et al., 2020). We assessed model performance via the area under the receiver operating characteristic curve (ROC) using the auc function of the "pROC" package (Robin et al., 2011); we considered ROC area under the curve values between 0.7 and 0.8 to be moderate, and those between 0.8 and 0.9 to be good (Mandrekar, 2010).

We used zero-inflated negative binomial mixed regression (Nickel et al., 2020; Suraci et al., 2019) to model the number of coyote reports (of either conflict or observation) received per park or park area per week between the weeks of September 23, 2018, and July 18, 2021. We only considered the coyote reports submitted following the first aversive conditioning event in each park. This model comprises a zero-inflated submodel to assess the probability that coyotes were reported on a certain park–week combination via a logistic regression, and a conditional submodel that assessed the abundance of coyote reports per park (or park area) per week using a negative binomial regression. Potential explanatory fixed-effect variables for this response variable included coyote season, year, and the last aversive conditioning treatment type prior to the reporting week if aversive conditioning was conducted in the eight weeks (56 days) prior to the week being evaluated. We also investigated the role of the number of days since the last aversive conditioning engagement, the number of aversive conditioning engagements of coyotes by contractors in the eight weeks prior to a reporting week (tallied separately for each park or park area), and the number of reports of coyote activity made to 311 in the eight weeks prior to the reporting week (also tallied separately) as potential fixed effects, and included park or park area as a random effect in all our models. We built models using the "glmmTMB" function of the glmmTMB package (Brooks et al., 2017). We evaluated predictors based on their AIC_c score, their 85% CIs, and their correlation coefficients as described above. We evaluated model fit using the r^2 function of the "performance" package (Lüdecke et al., 2021), which provides pseudo-R^2 adapted to zero-inflated GLMMs (Johnson, 2014; Nakagawa & Schielzeth, 2013). All statistical analyses were carried out using R 4.1.0 (R Core Team, 2021).

RESULTS

Coyote management plan review

Among the 72 management plans that we reviewed (Appendix S1: Table S1), most were from California (35 of 72; 49%). All the management plans recommended public education (e.g., how to differentiate normal vs. unusual coyote behavior), preventing human–coyote conflicts by reducing attractants, keeping pets safe via containment or leashing, using deterrents on private property, and knowing how to respond during a coyote encounter. All but one plan recommended the use of hazing of multiple types. Specific actions for low-intensity hazing (e.g., waving arms, motion-activated lights, shouting, and using noisemakers) by community members were recommended in 68 plans (94%) and by city staff and contractors in 8 plans (11%). When warranted by bold coyote behavior, a similar number of plans recommended moderate-intensity hazing that included throwing projectiles or spraying water or chemical deterrents; 66 plans (92%) recommended use by community members and 8 plans (11%) recommended use by professionals. High-intensity hazing involving projectiles launched by a device (e.g., slingshot or paintball gun) was recommended for community members in just 3 plans (4%) and for professionals in 14 plans (19%) as responses to coyotes following aggression toward people or dogs. About half of the plans ($n = 37$, 51%) encouraged the engagement of community members to address human–coyote conflict with community-led programs. Almost all plans ($n = 70$, 97%) recommended the targeted lethal removal of coyotes that were highly aggressive toward people ($n = 23$, 32%), attacked a pet ($n = 24$, 33%), or attacked a person ($n = 12$, 17%). Only one management plan (1%) recommended the relocation of aggressive individuals, whereas 40 management plans (56%) discouraged the use of this technique.

Many plans contained information about the implementation of hazing that was consistent with learning theory. About half of the plans recommended that hazing be conducted so that: it was obvious that the threat came from a person ($n = 35$, 49%); hazing should not stop until the coyote left the area ($n = 30$, 42%); be continued over the long term ($n = 34$, 47%); it included different people using different techniques to reduce habituation ($n = 41$, 57%). However, only five plans (7%) recommended the proactive behavior of hazing coyotes every time that a person sees them. Although half of the plans ($n = 34$, 47%) recommended that hazing effort should be exaggerated at the commencement of the hazing program, more plans ($n = 38$, 53%) included a decision framework where the intensity of responses to coyotes gradually increased with the frequency and degree of conflict.

Aversive conditioning in Calgary

Between September 25, 2018, and July 17, 2021, a total of 765 aversive conditioning events were conducted by contractors in 72 parks in the City of Calgary. The number of aversive conditioning events conducted per park ranged from 1 to 53 ($\bar{x} = 10.6$, $SD = 12.7$). The distribution of aversive conditioning events was not significantly different between seasons, with an average per year of 77.7 events in the breeding season ($SD = 11.6$), 97.7 during pup-rearing ($SD = 50.6$), and 79.0 ($SD = 18.4$) during dispersal ($F_{2,6} = 0.37$, $p = 0.71$). Between May 2, 2018, and July 21, 2021, within the same parks, 911 reports of coyote activity were submitted to the civic call center; the number of reports per park ranged from 0 to 74 ($\bar{x} = 12.7$, $SD = 13.4$). The distribution of coyote activity reports was not significantly different among coyote seasons, with an annual average of 85.3 reports during the breeding season ($SD = 75.1$), 102.0 reports during the pup-rearing season (SD = 92.6), and 82.0 (SD = 58.8) reports during dispersal ($F_{2,7} = 0.07$, $p = 0.94$).

When the immediate reaction of coyotes to an aversive conditioning event was known ($n = 736$; Table 2), coyotes commonly left the area without stopping to look behind them (response = 1, $n = 353$; 48.0%), or delayed leaving for a few moments without letting the contractors get close to them and eventually leaving the area (response = 2, $n = 254$; 34.5%). In approximately 14.8% of events ($n = 109$), coyotes delayed leaving and required multiple treatments, occasionally challenging the handler's dog without leaving and requiring additional aversive conditioning ($n = 17$; 2.3%). On three occasions (0.4%), a coyote attacked or attempted to attack a wildlife professional or their dog during an aversive conditioning event.

We found that the probability of coyote observation by contractors increased by 11.08–11.2 times with each additional aversive conditioning event in the week prior to an event and by 57%–58% with each additional day since the last aversive conditioning engagement (Table 4, Figure 1a; Appendix S3: Table S1). The probability of coyote observation by contractors also increased by 37% during the pup-rearing season (relative to the breeding season), and by 22% over years. We found that the probability of coyote observation by contractors increased by 26%–36% when the last aversive conditioning event conducted involved shots only (relative to when only working dogs were present; Figure 1a; Appendix S3: Table S1), and by 48%–60% when a chalk ball was shot and a working dog was present (relative to when only working dogs were present). The fixed and random effects of our top models together explained between 61.9% and 62.3% of the total variance and resulted in good values for ROC area under the curve (0.898–0.900).

Of the 72 parks where aversive conditioning was conducted, retreats by coyotes (Categories 1 and 2; Table 1) were recorded in 68 (94.4%) parks. The probability of coyote retreat (Categories 3, 4, or 5; Table 2) decreased by 22% with each additional day since the last aversive conditioning event (Table 4, Figure 1b; Appendix S3: Table S1), by 77% when a chalk ball was shot in the event being evaluated (relative to when only working dogs were present), and by 97.5% when a chalk ball was shot and a working dog was present in the event being evaluated (relative to when only working dogs were present). The probability of coyote retreat increased by 29% with each additional aversive conditioning event in the eight weeks prior to an event. The marginal R^2 values suggested that 38.5%–39.8% of the variance in the

TABLE 4 Summary of logistic regressions top models output for binary response of coyotes to aversive conditioning (resist = 0, retreat = 1) and the type of reports of coyote activity made to 311 (observation = 0, conflict = 1) in Calgary, Alberta, between September 2018 and July 2021.

Behavioral metric (response variable)	n	Model terms	df	ΔAIC_c	w_i	Marginal R^2	Conditional R^2	AUC
Coyote presence, as assessed by contractors	1355	AC + Days + Prior treatment + Year	7	0.00	0.188	0.589	0.620	0.900
		AC + Days + Prior treatment + Season	8	0.38	0.155	0.595	0.623	0.899
		AC + Days + Prior treatment	6	1.97	0.070	0.591	0.619	0.898
Response of coyotes to aversive conditioning	641	AC + Days + Treatment	6	0.00	0.168	0.397	0.522	0.913
		Days + Treatment	5	0.74	0.116	0.398	0.508	0.908
		AC + Treatment	5	1.46	0.081	0.385	0.508	0.911
Response of coyotes to aversive conditioning, when aversive conditioning had been conducted in the 8 weeks prior to an event	562	AC + Treatment	5	0.00	0.123	0.420	0.541	0.920
		Treatment	4	0.99	0.075	0.423	0.524	0.916
		AC + Treatment + Prior treatment	7	1.41	0.061	0.427	0.546	0.922
Type of coyote reports	460	AC + Year	4	0.00	0.242	0.034	0.125	0.719

Note: The df, difference in Akaike information criterion corrected for small sample sizes (ΔAIC_c), AIC weight (w_i), marginal R^2, conditional R^2, and ROC area under the curve (AUC) are presented for each model. We only presented models within 2.0 AIC_c of the top model. Table excludes the intercept, and the random effect of park or park area included with each model. Model terms are as follows: AC, number of aversive conditioning events in the 7 days (presence model) or 56 days (all other models) prior to this event; Days, number of days since the last aversive conditioning engagement; Treatment, the aversive conditioning treatment; Prior treatment, last aversive conditioning treatment prior to the event; Season, seasons relevant to coyote ecology (breeding, pup-rearing, dispersal); Year, year of the event.

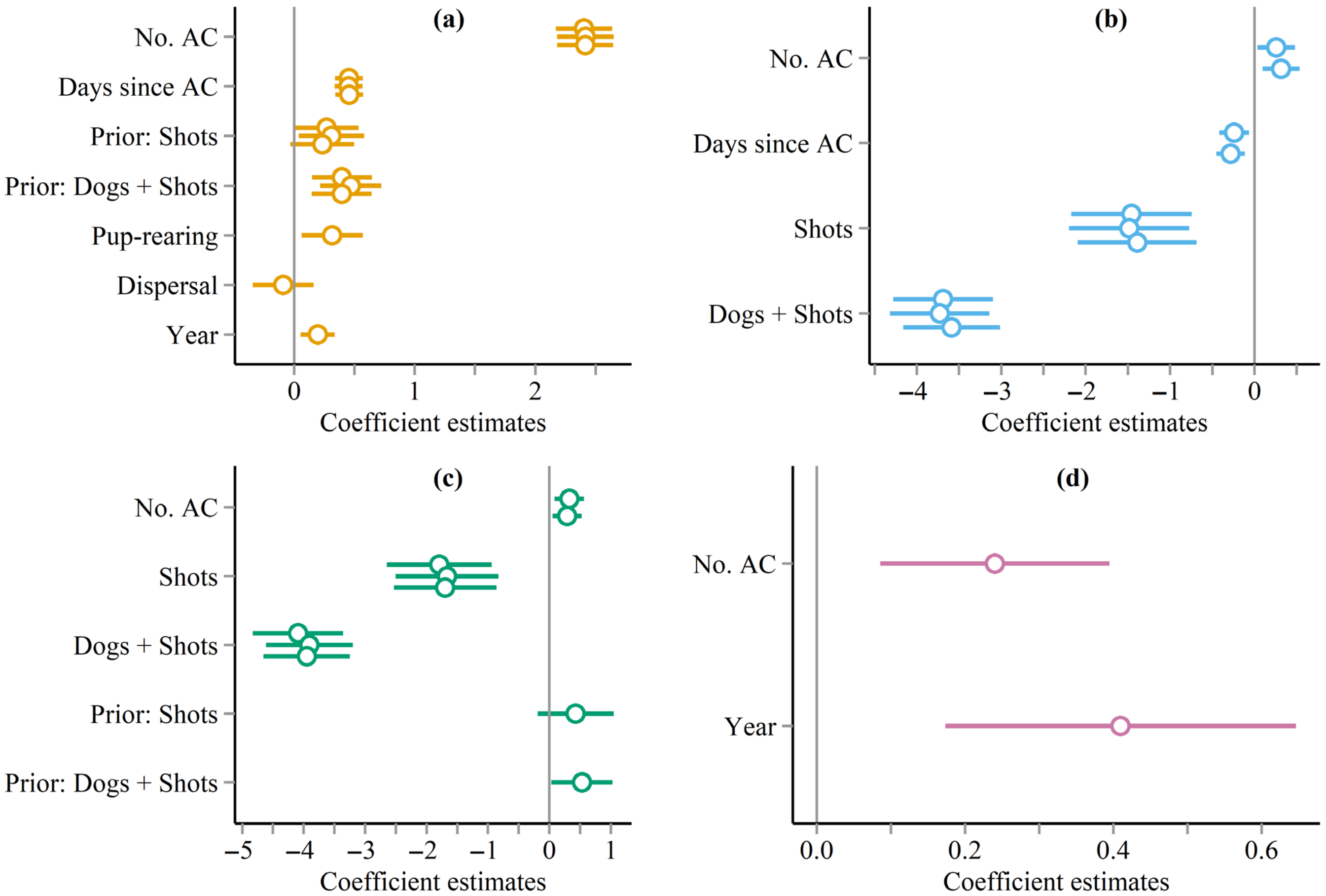

FIGURE 1 Coefficient estimates with 85% CIs for the top models from logistic regressions predicting (a) the presence of coyotes prior to an aversive conditioning event, (b) retreat by coyotes during an aversive conditioning (AC) event, (c) retreat during an AC event when another AC event had been conducted within the previous eight weeks, and (d) conflict reports about coyotes made by the public to the civic 311 service in the City of Calgary, Alberta, Canada between September 2018 and July 2021. Predictors in the top models included the number of aversive conditioning events in the week (a) or eight weeks (b–d) prior to an event (No. AC), the number of days since the last aversive conditioning engagement (Days since AC), the aversive conditioning treatment (coded as: 1, dogs were used, shots were not fired; 2, dogs were not used, shots were fired; 3, dogs were used, shots were fired), the last aversive conditioning treatment prior to the event (Prior, coded as described above), the seasons relevant to coyote ecology (coded as: 1, breeding; 2, pup-rearing; 3, dispersal), and the year of the event (Year). All continuous variables were scaled. The aversive conditioning treatments and the seasons relevant to coyote ecology were modeled as factors, with the treatments "Dogs used, No shots fired" and the breeding season as the reference categories.

top models was explained by the fixed effects, while the random effect of park alone explained an additional 11.0%–12.5% of the variance; this model yielded good ROC area under the curve values (0.908–0.913).

We explored the longer term reactions of coyotes to aversive conditioning by testing whether aversive conditioning treatments conducted in the eight weeks prior to an event affected the reaction of coyotes to subsequent aversive conditioning. We found that the probability of coyote retreat increased by 38% with each additional aversive conditioning event within the eight weeks prior to an event (Table 4, Figure 1c; Appendix S3: Table S1). The probability of coyote retreat increased by 70% when working dogs were present and chalk balls were shot in the most recent prior conditioning event (relative to when only working dogs were present). The probability of coyote retreat decreased by 83% when a chalk ball was shot during the event being evaluated (relative to when only working dogs were present), and by 98.3% when a chalk ball was shot and when a working dog was also present during the event being evaluated (relative to when only working dogs were present). The fixed and random effects of our top models together explained between 52.4% and 54.6% of the total variance and resulted in good values for ROC area under the curve (0.916–0.922).

Among reports submitted by the public to the civic 311 service, only observation-type reports were made in 13 of 69 (18.8%) parks where aversive conditioning was conducted, while only conflict-type reports were made in

3 of 69 (4.3%) parks; both coyote observations and conflicts were reported in the remaining 53 parks. We found that the probability of conflict reports increased by 27% with each additional aversive conditioning event in the eight weeks prior to a report, and by 51% with each year (Table 4, Figure 1d; Appendix S3: Table S1). This was a weak model, with the fixed effects explaining only 3.4% of the variance in the top model, while the random effect of parks explained an additional 9.1% of the variance; the top model yielded a moderate ROC value (0.719).

The two-part zero-inflated negative binomial model that separately examined predictors for the presence and abundance of coyote reports per park and week combination produced top models for presence (zero-inflated component) and abundance (conditional component) that included the number of prior reports of coyotes, season, and year (Table 5, Figure 2; Appendix S3: Table S1). The probability of coyote reports increased by 5.99–6.30 times with each additional report in the eight weeks prior, and by 2.14 times during the pup-rearing season (relative to the breeding season; Table 5, Figure 2a; Appendix S3: Table S1). The number of coyote reports per week increased by 49%–50% over years, by 14%–15% with every additional coyote reports, and by 49% the pup-rearing season (relative to the breeding season; Table 5, Figure 2b; Appendix S3: Table S1). These variables together with the random effect of parks explained between 19.0% and 19.8% of the variance in the models (Table 5).

DISCUSSION

Reports of bold urban coyotes are increasing throughout North America (Drake et al., 2020; Farr et al., 2023) and might be addressed with the behavioral management tools of hazing and aversive conditioning. To date, there is no standardization of these techniques for coyotes and few studies of their efficacy. In our review of 72 management plans for coyotes from across North America, most recommended the use of low-intensity hazing to manage coyotes, but only 14 plans (20%) recommended the use of high-intensity hazing that employed projectiles or dogs. In our analysis of a high-intensity aversive conditioning conducted by contractors in Calgary, Alberta, Canada, we found that high-intensity aversive conditioning treatments reduced retreat by coyotes at the time of engagement, but increased the probability of retreat during subsequent visits by contractors. We also found that the higher numbers of past aversive conditioning events in a park or park area predicted a greater probability of retreat by coyotes during aversive conditioning engagements, but also a greater probability of coyote presence as assessed by contractors and a greater probability of conflict reports by the public. Longer periods of time since the last aversive conditioning engagement predicted a greater probability of coyote presence and a reduced probability of retreat by coyotes during aversive conditioning engagements.

All but one of the 72 coyote management plans recommended some form of hazing to reduce conflict with coyotes, and most described the use of both low-intensity hazing (e.g., shouting, waving arms, approaching coyotes) and moderate-intensity techniques (e.g., throwing projectiles, spraying water or chemical deterrents). Plans often favored low-intensity treatments conducted by community members, which can produce an immediate change in coyote behavior (Bonnell & Breck, 2017), but may not produce longer term behavioral changes (Breck et al., 2017) and do not appear to change coyote distribution (Bonnell & Breck, 2017). Most management plans addressed some of the principles of effective punishment such as immediacy, frequency, and consistency of treatment (Domjan, 2014; Evans Ogden, 2021; Found & St. Clair, 2019), but half recommended a graduated approach beginning with mild treatments that increase in intensity as the frequency or severity of human–coyote conflict increases. Although such approaches might be perceived by the public as more humane than high-intensity aversive conditioning

TABLE 5 Summary of zero-inflated negative binomial regression top models output for number of coyote reports made to 311 per week and park combination ($n = 5037$) in Calgary, Alberta, between September 2018 and July 2021.

Model terms					
Occurrence of reports	**Abundance of reports**	**df**	**ΔAIC$_c$**	**Marginal R^2**	**Conditional R^2**
Report + Season	Report + Year	10	1.21	0.073	0.190
Report	Report + Season + Year	10	1.83	0.095	0.198

Note: The df, difference in Akaike information criterion corrected for small sample sizes (ΔAIC$_c$), marginal R^2, and conditional R^2 are presented for each model. We present only models within 2.0 AIC$_c$ of the top model. Table excludes the intercept, and the random effect of park or park area included with each model. Model terms are: Report, number of reports in the 56 days prior to this reporting week; Season, seasons relevant to coyote ecology (breeding, pup-rearing, dispersal); Year, reporting year.

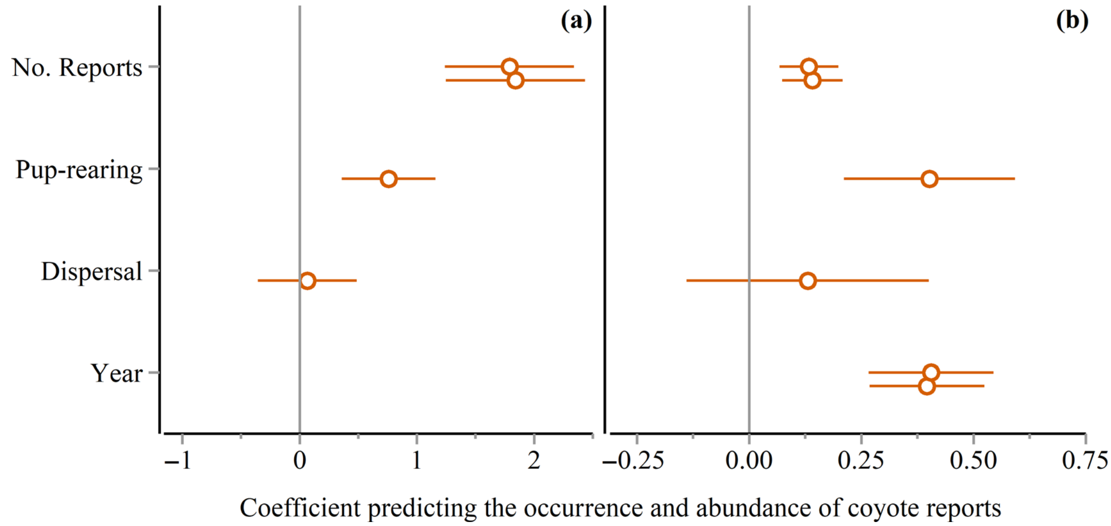

FIGURE 2 Coefficient estimates with 85% CIs from the top zero-inflated negative binomial regression models of the predictors of the weekly occurrence (a) and abundance (b) of coyote reports submitted by the public to the City of Calgary's 311 database (September 2018–July 2021). Predictors included the number of reports in the eight weeks prior to an event (No. Reports), the seasons relevant to coyote ecology (coded as: 1, breeding; 2, pup-rearing; 3, dispersal), and the year of the event (Year). All continuous variables were scaled. The seasons relevant to coyote ecology were modeled as factors, with breeding season as the reference category.

techniques (Sampson & Van Patter, 2020), gradual escalation of aversive stimuli is expected to produce habituation (Azrin et al., 1963; Banks, 1976; Domjan, 2014) and could decrease the efficacy of future interventions. Only the plan written for the City of Calgary, where we conducted our study, explicitly recommended the use of dogs to draw out coyotes for high-intensity treatment with projectiles launched from devices operated by wildlife professionals.

Our finding that most coyotes (83% of 734 events) retreated quickly from an aversive conditioning event was similar to a study in Denver, Colorado, where 71% of coyotes retreated from low-intensity aversive conditioning events conducted during a community-based hazing program (Bonnell & Breck, 2017). Moreover, the probability of coyote retreats in our study increased with the number of conditioning events at the same site conducted in the previous eight weeks. This result suggests a learning process consistent with the purpose of aversive conditioning for wildlife (Hopkins et al., 2010; Kloppers et al., 2005; Mazur, 2010) that has also been described for captive coyotes (Andelt et al., 1999; Young et al., 2019), and wild elk (*C. canadensis*; Found et al., 2018; Jones et al., 2021), lions (*P. leo*; Petracca et al., 2019), and macaques (*Macaca fuscata*; Honda et al., 2019). We found that longer periods of time since the last aversive conditioning engagement predicted a greater probability of coyote presence and a reduced probability of retreat from aversive conditioning, which is also consistent with the studies of captive coyotes (Young et al., 2019) and wild elk (Jones et al., 2021). In elk, individuals categorized as having bolder temperaments responded more rapidly to both the onset and elimination of aversive conditioning (Found & St. Clair, 2018).

Evidence from our study that the effects of aversive conditioning decline over time highlights the need for frequent aversive conditioning interventions, which likely interacts with conditioning intensity. There may be an upper limit to conditioning frequency because intermediate frequencies generated the greatest response to aversive conditioning in elk (Found et al., 2018). Somewhat paradoxically, the most intensive aversive conditioning events in Calgary that used both chalk balls and a dog were associated with bolder coyote responses. Presumably, this occurred because only the boldest coyotes remained in the area long enough for these treatments to be used. Nonetheless, the frequency of these high-intensity treatments increased retreat probability in subsequent weeks, as would be predicted by the principles of effective punishment, for which higher initial intensity of aversive conditioning is more likely to initiate a sensitization process while low-intensity conditioning could cause habituation (Blumstein, 2016; Domjan, 2014). Studies of black bears have shown similar responses to high-intensity conditioning that involved projectiles (Homstol, 2011; Mazur, 2010).

Another paradoxical result from our study is that a greater number of past conditioning treatments increased the probability of coyote presence as assessed by contractors. This result may reflect the clustered nature of coyote presence and reports within parks, but it may also forewarn of habituation to conditioning or the presence of food sources. In a study of captive coyotes, an increase in the cumulative number of hazing events for a pair of coyotes reduced the time they spent avoiding people (Young et al., 2019). Both results reinforce the view that aversive conditioning does not change the distribution of coyotes in urban areas (Bonnell & Breck, 2017; Breck et al., 2017) and suggest that managers should complement aversive conditioning with other management techniques. The most important of these is public education to reduce food availability to urban coyotes and prevent food-conditioned animals, which was recommended by all of the municipal management plans that we reviewed. Several authors have shown or speculated that food conditioning generally causes conflict in coyotes (Carbyn, 1989; Lukasik & Alexander, 2011; Schmidt & Timm, 2007), and this mechanism is prevalent in other carnivores (e.g., Gunther, 1994; Herrero, 2018; Lewis et al., 2015; Mohammadi et al., 2019; van Bommel et al., 2020). Studies of conflict in other species also emphasize the need to prevent wildlife from accessing human sources of food (Espinosa & Jacobson, 2012; Lackey et al., 2018; Proctor et al., 2018; Purcell et al., 2012). For coyotes, these sources could include intentional feeding, but more often involve inadvertent feeding via garbage, compost, fruit trees, and bird feeders. Aggressive prevention of the anthropogenic attractants that contribute to bold behavior reduces the need for lethal management. Although targeted lethal removal of problem individuals can rapidly reduce human–coyote conflicts (Breck et al., 2017) and was recommended in all but two of the management plans, it is increasingly contentious with the public (Drake et al., 2020; Jackman & Rutberg, 2015; Martínez-Espiñeira, 2006). Independent of attractants, coyote boldness varies with season and appears to be increasing over time. As a seasonal pattern, we found that coyote boldness increased during the pup-rearing season when coyotes are defending vulnerable young, which is consistent with several other studies (Baker & Timm, 2016; Farr et al., 2023; Lukasik & Alexander, 2011; Quinn et al., 2016; Timm, 2006). We also found that both the probability of conflict reports and the number of reports increased between years, again similar to the findings of others (Drake et al., 2020; Farr et al., 2023).

Our work has some important limitations that invite further study of aversive conditioning as a tool for managing urban coyotes. First, we treated parks and areas within large parks as independent units in our analyses, but some coyotes undoubtedly traveled among these areas. Consequently, we cannot be sure that coyotes found at the same location were repeatedly exposed to conditioning treatment even when these occurred in the same area over successive days. The second limitation of this study is that aversive conditioning could occur only on city-owned property, which prohibited contractors from pursuing coyotes on private property where food and shelter were sometimes available (C. C. St. Clair, personal observation). Third, our study did not quantify an impression by several authors that coyotes responded by retreating immediately as contractors approached following an initial aversive conditioning event. Future studies might record a preconditioning response to test this impression. Fourth, because our data were collected as part of an active management program, we could not designate some parts as controls, which limits the interpretation of conditioning treatment (Snijders et al., 2019). A final potential limitation is that the data were collected by contractors (for contractor actions and coyote responses) and city employees (for 311 reports) who did not anticipate our use of the data.

Like other studies of aversive conditioning, logistical constraints prevented us from consistently applying the principles of effective punishment as described by learning theory (Domjan, 2014; Evans Ogden, 2021; Found & St. Clair, 2019). Calgary's high-intensity conditioning applied the principles of evolutionary relevance (pursuit and fear), high initial intensity (chalk balls and dogs), and consistency (similar procedures with each engagement), but events could not be performed immediately and conditioning was signaled by the appearance of contractors in high-visibility vests. Even without the cue of familiar clothing, vehicles, and dogs, coyotes likely have the capacity to recognize individual people, which is well known in domestic dogs (*Canis familiaris*; Huber et al., 2013) and species as diverse as American crows (*Corvus brachyrhynchos*; Marzluff et al., 2010), domestic sheep (*Ovis aries*; Knolle et al., 2017), and archerfish (*Toxotes chatareus*; Newport et al., 2016). A final principle of punishment (i.e., the use of rewards for alternative behavior; Domjan, 2014) is difficult to achieve in any wildlife setting, but coyotes may perceive the cessation of treatment when exhibiting the desired behavior as a reward, similar to expectations for bears subjected to aversive conditioning (e.g., Edwards, 2023; Homstol, 2011). Future work could aim to employ more of these principles for effective aversive conditioning (Domjan, 2014; Evans Ogden, 2021; Found & St. Clair, 2019).

CONCLUSIONS

Our study demonstrated that high-intensity aversive conditioning, as conducted by contractors and their working dogs, increased the probability of subsequent retreats by coyotes. Similar aversive conditioning techniques used proactively on all coyotes might reduce the occurrence of bold behaviors in urban areas. Aversive conditioning should be used in combination with management that educates the public to promote coyote reporting to civic databases, discourages wildlife feeding, and improves waste disposal in order to prevent food-conditioned coyotes. Although most coyote management plans stated that highly aggressive animals should be removed, there was less consistency in recommendations for bold animals. More study is urgently needed of nonlethal techniques for managing human–wildlife conflict, particularly for carnivores in urban areas.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest. Data about contractor actions and coyote responses were collected by Animal Damage Control. Data about public reports to 311 were collected by the City of Calgary. Both data sets were provided to the authors to support scientific study without cost or remuneration for any party.

DATA AVAILABILITY STATEMENT

Data and code (Lajeunesse et al., 2023) are available from Figshare: https://doi.org/10.6084/m9.figshare.20682394.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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