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RESEARCH ARTICLE

Coexistence across space and time: Social-ecological patterns within a decade of human-coyote interactions in San Francisco

Christine E. Wilkinson[1,2] | **Tal Caspi**[3] | **Lauren A. Stanton**[1] | **Deb Campbell**[4] | **Christopher J. Schell**[1]

[1]Department of Environmental Science, Policy, and Management, University of California, Berkeley, California, USA

[2]California Academy of Sciences, San Francisco, California, USA

[3]Department of Environmental Science and Policy, University of California, Davis, California, USA

[4]San Francisco Animal Care and Control, San Francisco, California, USA

Correspondence
Christine E. Wilkinson
Email: christine.wilkinson@berkeley.edu

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Abstract

1. Global change is increasing the frequency and severity of human-wildlife interactions by pushing people and wildlife into increasingly resource-limited shared spaces. To understand the dynamics of human-wildlife interactions and what may constitute human-wildlife coexistence in the Anthropocene, there is a critical need to explore the spatial, temporal, sociocultural and ecological variables that contribute to human-wildlife conflicts in urban areas.
2. Due to their opportunistic foraging and behavioural flexibility, coyotes (*Canis latrans*) frequently interact with people in urban environments. San Francisco, California, USA hosts a very high density of coyotes, making it an excellent region for analysing urban human-coyote interactions and attitudes toward coyotes over time and space.
3. We used a community-curated long-term data source from San Francisco Animal Care and Control to summarise a decade of coyote sightings and human-coyote interactions in San Francisco and to characterise spatiotemporal patterns of attitudes and interaction types in relation to housing density, socioeconomics, pollution and human vulnerability metrics, and green space availability.
4. We found that human-coyote conflict reports have been significantly increasing over the past 5 years and that there were more conflicts during the coyote pup-rearing season (April–June), the dry season (June–September) and the COVID-19 pandemic. Conflict reports were also more likely to involve dogs and occur inside of parks, despite more overall sightings occurring outside of parks. Generalised linear mixed models revealed that conflicts were more likely to occur in places with higher vegetation greenness and median income. Meanwhile reported coyote boldness, hazing and human attitudes toward coyotes were also correlated with pollution burden and human population vulnerability indices.
5. *Synthesis and applications*: Our results provide compelling evidence suggesting that human-coyote conflicts are intimately associated with social-ecological heterogeneities and time, emphasizing that the road to coexistence will require socially informed strategies. Additional long-term research articulating how the

social-ecological drivers of conflict (e.g. human food subsidies, interactions with domestic species, climate-induced droughts, socioeconomic disparities, etc.) change over time will be essential in building adaptive management efforts that effectively mitigate future conflicts from occurring.

KEYWORDS

carnivore, coexistence, community science, coyote, human-wildlife conflict, human-wildlife interactions, social-ecological, urban wildlife

1 | INTRODUCTION

Humans have been living alongside and interacting with wildlife for millennia. However, unprecedented global change is increasing the frequency and severity of human-wildlife interactions relative to historical patterns by pushing wildlife and people into increasingly resource-limited, yet shared spaces (Abrahms, 2021). A growing body of literature demonstrates how urbanisation (Schell et al., 2021; Soulsbury & White, 2015) and climate change (Abrahms, 2021; Pecl et al., 2017), in combination with human attitudes and activities (Dickman et al., 2013; Penteriani et al., 2016), contribute to the intensification of human-wildlife conflicts worldwide. For example, heatwaves can lead to crop, livestock and fisheries damage by altering the distribution and foraging behaviour of both terrestrial and marine mammals (Lamarque et al., 2009; Santora et al., 2020). Most recently, the COVID-19 pandemic demonstrated the swiftness with which wildlife can respond to alterations in human behaviour and activity in ways that engender conflict. This phenomenon was particularly acute in urban centers, which documented widespread behavioural shifts in some species including increased aggression, elevated diurnal activity and greater use of urbanised areas compared to before the pandemic (Manenti et al., 2020; Miraglia & Di Brita, 2022; Vardi et al., 2021). Heightened spatiotemporal overlap between wildlife and people in cities intensifies opportunities for human-wildlife interactions, including conflict. Accordingly, there is a critical need to better understand the spatial, temporal and social variables that give rise to human-wildlife conflict in urban environments and use this information to develop and adopt holistic policies aimed toward coexistence.

Various ecological and social mechanisms contribute to the dynamics of human-wildlife conflict in cities. Species' life history, phenology, space-use and diet lead to an uneven distribution of conflict in space and time and among species (Soulsbury & White, 2015). For example, conflict in urban systems is more likely to involve species that live in high densities (Perry et al., 2020), have larger body sizes (Nyhus, 2016) and whose ranges significantly overlap with people (Fidino et al., 2022; Kretser et al., 2008). Conflict is also more likely to occur proximate to urban green spaces (Poessel, Gese, et al., 2017) and to arise at times of year that correspond with significant life-history events of the focal species (e.g. denning, hyperphagia, Lukasik & Alexander, 2011; Zarzo-Arias et al., 2021).

Although ecological variables influence human-wildlife interactions, the key determining factors of interaction outcomes are people, who provide the socio-economic, political and cultural context within which conflict exists (Dickman, 2010; Peterson et al., 2010; Soulsbury & White, 2015; Wilkinson et al., 2021). These sociocultural contexts influence individual and broad-scale actions toward wildlife, at the root of which are human perceptions of wildlife shaped by past experiences, beliefs and values that determine whether people view animals as beneficial or harmful (Dickman, 2010). Perceptions are further informed by diverse social practices including religious traditions, cultural norms, and news and social media, which can differ among groups and shift over time (Schell et al., 2021).

As with people, wildlife living in cities are exposed to high levels of heterogeneity in environmental conditions. Green space, pollution and housing density can vary dramatically across neighbourhoods as a function of socioeconomic inequities (Schell et al., 2020). For example, urban animals may be exposed to different levels of pollutants and hazards in different parts of the city due to systemic societal inequities (i.e. poverty and gentrification) that unevenly distribute pollution burdens across the city (Murray, Buckley, et al., 2022; Schell et al., 2020). More specifically, historically redlined and poorer neighbourhoods often have higher pollution burdens (e.g. Schuyler & Wenzel, 2022), so it follows that wildlife living in these neighbourhoods also have greater exposure and may experience subsequent physiological effects, such as compromised immune function and elevated disease risk (Bradley & Altizer, 2007; Sanchez et al., 2020), which can exacerbate conflict with people (Murray et al., 2016). Within-city heterogeneity in environmental conditions and resource availability driven by socioeconomic factors may thus also result in spatial variation in conflict (Schell et al., 2021). Accordingly, examining both conflict and urban residents' attitudes and behaviour toward wildlife in relation to underlying heterogeneity in social and ecological factors is key to developing applied strategies that help mitigate future conflicts.

In urban environments throughout North America, coyotes (*Canis latrans*) are arguably the most notorious species involved in human-wildlife conflicts (see Alexander & Quinn, 2012; Elliot et al., 2016). Coyotes are a highly adaptive species due to their generalist dietary and habitat preferences (Poessel, Mock, et al., 2017) and relatively plastic life-history traits (e.g. compensatory reproduction and immigration, Gese, 2005; Sacks, 2005). As a result, coyotes occupy most major cities across the North

American continent (Poessel, Gese, et al., 2017) and are quickly becoming established in Central America (Monroy-Vilchis et al., 2020). Urban coyotes typically experience reduced predation and less intensive lethal control by humans compared to their non-urban counterparts (Gehrt et al., 2009), which, alongside additional human actions like direct and indirect feeding, may contribute to increased levels of boldness and exploratory behaviour in urban coyotes (Breck et al., 2019; Brooks et al., 2020). Cognitive abilities like learning (Schell et al., 2018; Young et al., 2019), behavioural flexibility (Murray & St. Clair, 2015; Stanton et al., 2021; Van Bourg et al., 2022) and navigation of spatially complex urban features (Niesner et al., 2021) likely enable coyotes to capitalise on the use of anthropogenic resources while also helping some individuals to avoid sources of mortality (e.g. vehicular collisions, Murray & St. Clair, 2015). However, these same behavioural and cognitive traits can exacerbate conflict scenarios with humans (Barrett et al., 2019), which have risen over the last several decades (Baker & Timm, 2017; Bombieri et al., 2018; Quinn et al., 2016; Timm et al., 2004). The use of inflammatory language (Draheim et al., 2021) and sensationalisation of coyotes in the media (Alexander & Quinn, 2011) has perpetuated negative perceptions and desired removal of coyotes by some in urban spaces (Draheim et al., 2021). Conversely, animal welfare advocates oppose the lethal removal of coyotes (Timm & Baker, 2007) and other urban residents even hand-feed coyotes, believing that feeding the animals helps them to survive (Erickson, 2010). In the face of such polarised viewpoints regarding coyotes, many cities have instituted coyote reporting systems to better monitor human attitudes and interactions with coyotes, with the hope that an improved understanding of this complex relationship will help reduce conflict and improve coexistence (Farr et al., 2022).

Although more robust empirical population estimates through genetics are needed, it has been suggested that San Francisco, California has one of North America's highest densities of coyotes (San Francisco Animal Care and Control, pers. comm.; Jonathan Young, pers. comm.). San Francisco is also one of the most gentrified cities in the USA, with a high degree of within-city heterogeneity in concentrations of wealth and pollutants (Cal Enviro Screen 4.0), factors which have been hypothesised to dramatically influence types and extremity of urban human-wildlife interactions (Murray, Buckley, et al., 2022; Schell et al., 2021). Additionally, although coyotes are native to San Francisco, their populations went locally extinct due to a combination of poisoning, hunting, habitat loss and urban expansion (Todd, 2018), with the last individual reported in Golden Gate Park in 1925 (Presidio Trust, 2015). However, in the early 2000s, coyotes began to recolonise San Francisco (Sacks et al., 2006), and it is believed that there are close to 100 individuals currently occupying the city (Jonathan Young, pers. comm; San Francisco Animal Care and Control, pers. comm.). Although many other cities and jurisdictions in California commonly trap and euthanise coyotes upon complaint from citizens, San Francisco Animal Care and Control (SFACC) instead has a coexistence policy in which they will leave coyotes alone except in very extreme circumstances, such as in the case of a coyote repeatedly approaching young children in 2021 (SFACC, pers. comm.). The recent recolonisation of San Francisco by coyotes, in conjunction with the city's ongoing human population densification, gentrification and unique coyote coexistence policy, creates an optimal study area for understanding the social-ecological predictors and correlates of urban human-coyote interactions.

Here, we used a community-curated longitudinal data source from San Francisco Animal Care and Control to summarise a decade of coyote sightings and human-coyote interactions in San Francisco, and to characterise spatial patterns of attitudes and interaction type in relation to housing density, socioeconomics, and green space availability. We hypothesised that (1) coyote sightings, conflict reports and varying human attitudes would have observable contextual and spatial differences and (2) these differences would be associated with a variety of social and ecological factors (Table 1). Finally, we explore the successes, challenges, biases and implications of using community-curated data sources to understand human-wildlife interactions, and how such datasets and their social-ecological correlates can be used to improve human-wildlife coexistence in urban environments.

2 | METHODS

2.1 | Study site

This study was carried out in San Francisco, California (37.7749° N, 122.4194° W), a relatively small city with an area of only 46.87 mi^2 but the third most-densely populated city in North America (Townsend & Ellis-Young, 2018). San Francisco has a Mediterranean climate with temperate summers and cool, rainy winters. The average temperature ranges from a low of 47–58 °F in winter (December and January) to a high of 55–71 °F in late summer (August–September).

2.2 | San Francisco animal care and control coyote sightings database

2.2.1 | Database history and advertisement

The primary dataset we used for these analyses was the San Francisco Animal Care and Control coyote sighting database. Specifically, we used data from January 2012 to June 2022. The first report for the SFACC coyote sighting database was in 2006. When the database began, community members had the option to call a hotline or email SFACC to report their coyote sightings and any interactions they observed or experienced. By 2011, data collection was consistently initiated in earnest, and by 2017, data collection was standardised to include the same basic information across reports. Starting in 2017, an online submission form for coyote sightings began (https://www.sfanimalcare.org/living-with-urban-wildlife/coyote-sightings/). This is now the primary method by which SFACC receives coyote sighting reports, but phone and email submissions

TABLE 1 Hypotheses related to coyote sightings, coyote conflict reports and human attitudes.

Variable	Hypotheses and predictions	Rationale
Urban green space	Closer proximity to urban e is correlated with 1. more numerous and clustered coyote sightings overall, 2. more numerous and clustered conflict reports and 3. more coyote sighting records with positive human attitudes toward coyotes than in residential areas.	*Overall mechanisms*: Urban coyote home ranges are associated with natural habitat (green spaces) and coyotes preferentially select for natural and undeveloped lands[1]. *Specific pathways*: • Coyote conflicts take place more often in green spaces than in the urban core of the city[2]. • Coyote conflicts have been reported more often than expected in the development and open space (i.e. parks) green spaces and less often than expected in natural and agricultural areas[3]. • Bolder behaviour has been reported more frequently in areas with higher proportions of mowed land cover[4]. • Conflict-indicative coyote behaviour has been found to be most prevalent in spaces that are at the interface of natural and developed urban areas, specifically in less-developed areas that were mowed or otherwise not naturally vegetated[4]. • Use of urban green spaces can correlate with greater connectedness and positive emotions toward parks and nature[13], which can influence human attitudes toward urban wildlife.
Pollution burden (percentile)	Higher pollution burden is correlated with 1. fewer and more dispersed coyote sightings overall, 2. fewer and more dispersed conflict reports and 3. more coyote sighting records with negative human attitudes toward coyotes.	*Overall mechanisms*: Pollution burden is an indicator (and driver) of both human and wildlife health and well-being[6]; thus, wildlife such as coyotes may not be as likely to choose to live in locations with higher pollution burden. *Specific pathways*: • Pollution burden is higher in places of historical human disenfranchisement[6]; thus, people in these locations may not have as much leisure or recreational opportunities or accessibility to encounter coyotes[7]. • Urban parks are less likely to have a high pollution burden, and coyotes have been reported to be more likely sighted in parks[2].
Human population vulnerability characteristics (percentile)	Higher human population vulnerability is correlated with 1. fewer and more dispersed coyote sightings overall, 2. fewer and more dispersed conflict reports and 3. fewer coyote sighting records with negative human attitudes toward coyotes.	*Overall mechanisms*: Access to green space and nature is often inequitably distributed along axes of wealth, power and race. Areas of higher human population vulnerability may have limited access to green space[18,19] and thus be less likely to have opportunities for human-coyote interaction. *Specific pathways*: • Disparities in human population vulnerability could lead to differences in how people perceive interactions with wildlife and in motivation to report conflict to governing bodies[20]. • Disparities in human population vulnerability are linked to green space access, wildlife presence, and human-wildlife interactions[6,8]
Median income	Higher median income is correlated with 1. more numerous and clustered coyote sightings overall, 2. more numerous and clustered conflict reports, 3. more coyote sighting records with negative human attitudes and fear than in locations with lower average annual income and 4. more hazing of coyotes.	*Overall mechanisms*: Coyotes are more likely to colonise and less likely to disappear in more affluent areas, due to the luxury effect, whereby wealthier areas have greater levels of biodiversity[8]. *Specific pathways*: • Household income has been positively correlated with the probability of a human-coyote encounter[10]. • For some urban species, human-wildlife conflict was more likely to occur in high-income neighborhoods[11], which may mean higher income residents have more exposure to coyote hazing.
Housing density/ population density	Higher housing/population density is correlated with 1. more coyote sightings overall and 2. fewer coyote conflict reports.	*Overall mechanisms*: Less densely populated areas are most likely to contain coyotes[9]; thus, when a coyote enters a densely populated neighbourhood, the sighting may be perceived as a rarity and more likely to be reported. *Specific pathways*: • Coyotes reported in housing-dense areas (in which they are less likely to reside[9]) may be less likely to engage in conflicts and more likely to be traversing through. • Coyotes in housing-dense areas may be more likely to be seen due to more people on the landscape.
Normalised difference vegetation index (NDVI)	Higher NDVI is correlated with 1. more coyote sightings overall, 2. more coyote conflict reports and 3. more negative attitudes toward coyotes.	*Overall mechanism*: Coyotes are more likely to be found in green space[3], and to den in green space, particularly in dense vegetation[14]. *Specific pathways*: • Because of their higher prevalence in green space, coyotes will be more likely to be seen and more likely to engage in altercations with people and pets related to den protection. • Dogs (especially off leash) are more likely to be walked in green space (SFACC pers. comm.) and encounter coyotes in conflict-causing events.

TABLE 1 (Continued)

Variable	Hypotheses and predictions	Rationale
Roads	1. Road density is positively correlated with more sighting reports overall and fewer conflict reports. 2. Non-conflict coyote sighting reports are more likely to note coyotes walking within or crossing the street than conflict reports.	*Overall mechanisms*: Linear infrastructure, which are dense in cities, can have a wide range of effects on wildlife, from causing mortality to facilitating landscape navigation. *Specific pathways*: • Wildlife are known to use linear infrastructure for ease of movement; wildlife are also more visible to people and thus more notable for reporting when using roads[5].
Domestic dogs	1. Coyote sightings in which a domestic dog was present are more likely to be conflict reports. 2. Conflict reports are more likely than not to have involved a domestic dog. 3. Conflict reports are more likely than non-conflict sightings to involve off-leash (vs. on-leash) dogs. 4. People whose non-conflict coyote sightings involve a domestic dog are more likely to express negative or fearful attitudes regarding coyotes.	*Overall mechanisms*: Dogs and coyotes may be involved in actual or perceived altercations, which can be particularly prevalent forms of coyote interaction in urban areas due to people's use of public parks for dog walking. *Specific pathways*: • Most pet-attack reports have involved coyotes coming close to the house and attacking a pet, and most dog-related reports taking place in open space involved off-leash dogs[3]. • Coyotes have been known to attack off-leash dogs within yards[12]. • Bold coyote behaviours were described more frequently when dogs were mentioned, and aggressive coyote behaviours were described more frequently when cats or dogs were mentioned and when dogs were off leash[4].
Time and season	1. The proportion of coyote sightings that constitute conflict have increased over time. 2. The proportion of coyote sightings constituting conflict are highest during the COVID-19 lockdown period. 3. The proportion of coyote sightings that constitute conflict is higher during coyote pup-rearing season. 4. The proportion of coyote sightings that constitute conflict is higher during coyote breeding season. 5. The proportion of coyote sightings that constitute conflict is higher during the dry season. 6. Over time, the time of day of coyote conflict reports and non-conflict reports have shifted to temporally overlap more, and over time proportionately more conflict reports have occurred during the daytime hours.	*Overall mechanisms*: Seasonal resource needs and coyote reproductive and denning status can both influence coyote behaviours that may contribute to or be perceived as conflict. Seasonal and daily human activity are also significant drivers of human-coyote interactions. *Specific pathways*: • Most human-coyote conflicts took place during pup-rearing season, and most sightings took place during the breeding season[2]. • The prevalence of physical conflict with coyotes increased during the pup-rearing season[14]. • Coyote observations were reported more than twice as often during winter [when resources are scarce] than any other time of year, and conflicts increased more than 1.5× during this time compared to other times of year[3]. In California, the season of starkest resource scarcity is summer. • Attack reports in California were seasonal, with ⅔ occurring during the coyote pup-rearing season[15]. • Attacks on dogs were most common in the pup-rearing season[12]. • Bolder behaviour was higher during the pup-rearing season and increased over time[4]. • The greatest number of human-coyote encounters occurred during the coyote breeding season[16]. • Urban coyote boldness and involvement in conflicts may increase over time after the establishment of an urban population[4,16]. • The COVID-19 pandemic contributed to a number of trickle-down effects on wildlife activity, behaviour, and interactions with people, through both shelter-in-place and work-from-home policies.[17]
Human experience	1. People who have reported conflict have more negative or fearful attitudes regarding coyotes. 2. Negative opinions toward coyotes, or concern over living alongside coyotes, are more likely to be present in reports in which people express concern over child, adult, dog, and other pet safety. 3. Positive opinions toward coyotes are more likely to be expressed in non-conflict reports. 4. Negative or fearful attitudes regarding coyotes have increased over time.	*Overall mechanisms*: People's experiences with wildlife shape their overall perceptions and attitudes toward certain species. *Specific pathways*: • Negativity toward coyotes was much more common than other attitudes, and reports of bold or aggressive behaviour were more likely to express negative perceptions of coyotes[4].

Note: 1. Gehrt et al. (2009), 2. Lukasik and Alexander (2011), 3. Poessel et al. (2013), 4. Farr et al. (2022), 5. Benson et al. (2015), 6. Murray, Buckley, et al. (2022), 7. Ellis-Soto et al. (2022), 8. Schell et al. (2020), 9. Magle et al. (2016), 10. Wine et al. (2015), 11. Fidino et al. (2022), 12. Frauenthal et al. (2017), 13. Irvine et al. (2013), 14. Raymond and St. Clair (2023), 15. Baker and Timm (2017), 16. Drake et al. (2021), 17. Vardi et al. (2021), 18. Scopelliti et al. (2016), 19. Wolch et al. (2014), 20. Dickman (2010).

have continued simultaneously. An SFACC officer nearly always follows up with each reporter to assess their experience and confirm that their sighting was indeed a coyote.

San Francisco residents learn about submitting coyote sighting reports to SFACC via various avenues. Primarily, signage in park properties (e.g. regarding coyote activity alerts, coyote den site alerts, etc.) is put up by San Francisco Recreation and Parks. SFACC works with San Francisco Recreation and Parks to keep track of new and shifting coyote locations and sighting hot spots as coyotes colonise and establish in new areas over the years. SFACC officers also inform people who call the office how they can report sightings online and encourage them to share the coyote sighting webform. Additionally, SFACC includes the webform link in social media posts and in media stories, which have included print, online, TV and radio (e.g. Bartlett, 2021; Guilfoil, 2022).

2.2.2 | Logistics and ethics of participation in the database

For the online coyote sighting form, community members are invited to submit any of the following information: date, time, description and location of incident; whether a dog was involved and if it was leashed; physical description of the coyote including whether it had a tracking collar; additional notes and comments; and whether they would like more information from SFACC. Community members are also invited to submit media to accompany their report. Prior to submission, all participants who choose to submit their coyote sightings are informed by SFACC that their participation is voluntary and that their submissions may be used for research and/or education; thus, consent is implicit in participation in the organisation's monitoring effort. The SFACC coyote sightings database is also covered by San Francisco's Sunshine Ordinance (Chapter 67: The San Francisco Sunshine Ordinance of 1999) and the data used for this study are therefore publicly available. Our research was thus deemed exempt from Institutional Review Board approval by the University of California-Berkeley Office for the Protection of Human Subjects.

2.3 | Statistical analyses

2.3.1 | SFACC data cleaning and organization

San Francisco Animal Care and Control data were converted from pdf to spreadsheet. Occasional duplicate records were pared down to a single record. Where possible, data were geolocated to the exact geospatial point using addresses, intersections or specific location information provided. Using the descriptions of each record, we further classified the data to describe the number of coyotes involved in the report, whether the report was considered conflict, not conflict or unknown, as well as additional categories and descriptors on the nature of reported conflicts, opinions, feelings and attitudes expressed, and concerns for child and animal welfare I (Table 2). Prior to classifying the entire dataset, we conducted classifications on common subsets of the data ($n=40–50$ records each) and used any disagreements to iterate on our classification process until it was detailed enough to be reproducible. To assure reproducibility of the final categorisation descriptors, a random sample of additional records were categorised by an additional 1–3 people. A key element that emerged from this iteration process and assured reproducibility was binary classifications (rather than ranked or scaled classifications) of components of encounters, attitudes, opinions and coyote behaviours. We categorised reported coyote behaviours as aggressive, bold or skittish (Table 2). Hereafter, "conflict reports" refers to reports that were classified as conflict, "non-conflict reports" refers to the remainder of the reports, and "all reports" or "sightings" refer to the entire dataset.

2.3.2 | Temporal conflict trends

To understand temporal trends of conflict reports as compared to non-conflict reports while controlling for changes in numbers of overall reports over time, we used a generalised linear model to analyse the proportion of overall sightings that constituted conflict over time from 2017 (when the online form appeared) to 2022 across 3-month time periods. We then used 2-tailed *Z*-tests to determine whether there were differences in the proportion of sightings constituting conflict across the following binary time periods: (1) during prime pup-rearing season (April–June) versus outside of prime pup-rearing season, (2) during prime breeding season (December–March) versus outside of prime breeding season, (3) during the rainiest season (December–March) versus during the driest season (June–September) and (4) before the COVID-19 pandemic (January 2012–February 2020) versus during the COVID-19 pandemic (March 2020–June 2022). For each of these binary time periods, we analysed the data from the standardised [online form] time periods (2017–2022), and from the entire observation window (2012–2022), as an uncertainty measure.

To assess reported conflict at fine temporal scales (i.e. time of day), we used the 'overlap' package in R (Meredith & Maintainer, 2018) to determine the temporal overlap coefficient (dhat) between conflict and non-conflict reports, as well as between conflict reports at different time periods, for all records that included a time of occurrence. General changes over time and the effects of the COVID-19 pandemic on the fine-scale daily temporality of conflict reports were determined by comparing the smoothed bootstrapped mean overlap coefficient (10,000 resamples) and 95% confidence intervals between variables.

2.3.3 | Describing conflict and attitudes

We used descriptive statistics to explore the prevalence of conflict reports, types and characteristics of conflict, and attitudes.

TABLE 2 Classification scheme for categorizing San Francisco, California coyote sighting reports from 2012 to 2022 using their accompanying descriptive comments.

Qualitative categories and descriptors expressed	Criteria for assigning "yes" to a qualitative descriptor
Conflict (yes, no, unknown)	• Coyote(s) touching, following[a], stalking, chasing or attacking a person, pet, or domestic animal[b]. • Coyote(s) threatening (i.e. baring teeth, snarling, growling, etc.) a person, pet or domestic animal. • Coyote(s) killing a pet or domestic animal. • Coyote(s) struck by vehicle or described as disrupting traffic patterns. • Off-leash dog(s) chasing coyote(s).
Negative attitude/opinion (y, n)	• Person expresses a negative attitude or opinion about coyotes (including fear, anger and disgust). • Person expresses a desire for lethal control of coyotes. • Person expresses a desire for removal of coyotes.
Positive attitude/opinion (y, n)	• Person expresses a positive attitude or opinion about coyotes (including awe, excitement, complimenting their beauty or "cuteness"). • Person expresses a desire for coexistence with coyotes.
Concern for coyote wellbeing (y, n)	• Person expresses a concern about coyote safety, health or other wellbeing.
Understanding (actual or perceived) of typical coyote ecology and behaviour (y, n)	• Person expresses an understanding of "typical" coyote ecology and/or behaviour, either in general or in the context of the person's choices in the interaction/sighting. • Person expresses an understanding of or perception about long-term population or behaviour trends for coyotes in San Francisco or more generally.
Interest in receiving more information about coyotes and/or coyote management (y, n)	• Person expresses interest in learning more about coyotes, coyote management, and/or human-coyote interactions.
Human fear of or concern about coyotes (y, n)	• Person expresses fear, concern or nervousness about their encounter. • Person expresses fear, concern or nervousness about living alongside coyotes in general.
Mentions or describes coyote aggression (y, n)	• Report description includes information about the coyote showing aggressive behaviours, that is "the coyote was aggressive", "the coyote was snarling/growling/baring teeth/ears back/lunging".
Mentions or describes coyote boldness (y, n)	• Person describes an encounter with coyote(s) following closely/continuing behaviour in crowded spaces or spaces described as having many vehicles. • Person describes an encounter with coyote(s) following closely/continuing behaviour despite hazing attempts. • Person describes an encounter with coyote(s) running at/toward or chasing them starting from a far distance. • Person describes a coyote approaching or standing within 10 feet of a person/pet/domestic animal while in the presence of humans.
Mentions or describes coyote fear or skittishness (y, n)	• Person describes coyote running away, appearing scared and/or appearing startled.
Mentions an increase in coyote boldness and/or presence (y, n)	• Person describes any of the following or variations thereof: coyotes "getting bolder", "coyote populations increasing", "more coyote sightings and/or encounters than before"
Eating/biting or attempting to eat/bite human attractants including pets (y, n, likely, uk)	• Coyote(s) witnessed lunging within close range, biting, carrying away, and/or eating a pet or domestic animal. • Coyote(s) witnessed eating attractants such as dog or cat food, trash, compost, meat and so forth.
Coyote was hazed (y, n, uk)	• Person describes hazing the coyote(s) or watching it be hazed by other participants in the encounter. Hazing can include but is not limited to yelling or screaming, waving arms, honking car horn or air horn persistently, stomping, blowing a whistle, waving a stick or other object in conjunction with other hazing, using pepper spray or mace, and so forth.
Coyote moved on in response to hazing (y, n, uk, NA)	• Coyote(s) moved on (i.e. ran or walked away and did not return) in response to hazing.
Child followed/stalked/attacked (y, n)	• Person describes coyote(s) following, stalking, or attacking (i.e. lunging, biting) a child.
Crossing/standing in/walking down the street (y, n)	• Person describes a coyote standing in, walking down, and/or crossing the street (within the road).
Vehicle(s) involved (y, n)	• Person describes a coyote hit by a vehicle. • Person describes vehicles needing to adjust driving or traffic patterns to avoid hitting coyote(s) in the road.
Adult human followed/stalked/attacked (y, n)	• Person describes coyote(s) following, stalking, or attacking (i.e. lunging, biting) an adult human.
General concern about child welfare/safety (y, n)	• Person expresses concern for child welfare or safety, specifically (i.e. worried about their own child) or generally (i.e. worried about children in the community or the park in question).
General concern about adult welfare/safety (y, n)	• Person expresses concern for adult welfare or safety, specifically (i.e. worried about themselves) or generally (i.e. worried about adults in the community or the park in question).
General concern about dog welfare/safety (y, n)	• Person expresses concern for dog welfare or safety, specifically (i.e. worried about their own dog) or generally (i.e. worried about dogs in the community or the park in question).
General concern about welfare/safety of other pets and/or livestock (y, n)	• Person expresses concern for the welfare or safety of other (non-dog) pets or livestock, specifically (i.e. worried about their own pets/livestock) or generally (i.e. worried about pets/livestock in the community).

TABLE 2 (Continued)

Qualitative categories and descriptors expressed	Criteria for assigning "yes" to a qualitative descriptor
Says or implies that coyotes do not belong in the city/specific location (y, n)	• Person expresses that coyotes do not belong at all in the specific location, within San Francisco broadly or within cities generally. • Person expresses that coyotes do not belong untended/unregulated in the specific location, within San Francisco broadly or within cities generally.
Expresses frustration with management and/or inaction about coyotes (y, n)	• Person expresses frustration or anger over coyote presence, coyote management, or inaction regarding coyotes. Often directed at the authorities.
Person likely confirmed feeding/watering or attempting to feed/water coyotes or feral cats (y, n)	• Report describes seeing someone attempt or succeed at feeding or giving water to coyote(s) or feral cat(s). • Report describes food or water intentionally left out for coyote(s) or feral cat(s).

[a]Did not distinguish between following at near versus far distance as this was not discernable in most reports. Regardless of distance, following may be perceived as conflict.

[b]Did not distinguish between domestic and feral cats since human perception and apparent emotional impact tend to be similar for both.

We used Pearson's chi-square test to determine whether conflict reports were significantly associated with the presence of dogs, whether off-leash dogs were significantly associated with conflict, and whether certain attitudes and conflict experiences were associated with one another.

2.3.4 | Geospatial analyses and visualisation

For geolocated reports, we conducted analyses to determine whether the following covariates were correlated with reported conflict and/or attitudes: whether or not the sighting occurred in a park (National Park Service, SF Recreation and Parks), housing density (US Census 2020), Normalised Difference Vegetation Index (NDVI; Landsat 8), median household income (US Census 2020), road density (derived from US Census 2021), pollution burden percentile (Cal Enviro Screen 3.0) and human population vulnerability characteristics percentile (Cal Enviro Screen 3.0). Pollution burden is an index that is calculated from 13 metrics related to air quality, drinking water and groundwater characteristics, hazardous waste and traffic impacts. Human population vulnerability is an index that is calculated from 8 metrics related to human health and socioeconomics. To determine whether effects of vegetation greenness were different and/or stronger in the dry season, we calculated an averaged measure of dry season NDVI and an averaged measure of rainy season NDVI using data from each season in bothSwain et al., 2014 and 2021. Road density, housing density, and Cal Enviro Screen metrics have remained largely unchanged for San Francisco during the study period, so the most recent estimates were used.

We created spatial visualisations of sightings, conflict and attitudes, and we used Getis-Ord Gi* statistic (Getis & Ord, 2010) to determine local spatial clustering using ArcGIS Pro 3.0.2 (ESRI Inc, 2022). All analyses on social-ecological covariates were conducted in R v.4.2.2 (R Core Team, 2021). We then conducted descriptive analyses for reports within and outside of city parks. To better understand whether and how sociocultural and ecological factors are correlated with conflict reports, characteristics of conflict and non-conflict reports, and attitudes, we analysed reports across the remaining covariates with generalised linear models and generalised linear mixed-effects models (GLMM), using year as a random effect where applicable to control for variability in reporting over time.

We conducted the modelling analysis at three levels: (1) exact point, (2) 100 m buffer and (3) 500 m buffer, using a variation on a *pseudo-optimised single scale* approach (McGarigal et al., 2016) in which we evaluated multivariate models at each scale and used Akaike's information criterion (AIC, Burnham & Anderson, 2002) to determine the top candidate GLMMs and significant correlates at each scale. This approach was intended to determine if there were scale-related differences in covariate influence, since coyote interactions with people are likely to have both local and landscape-level drivers (Magle, Poessel, et al., 2014). These scales were chosen (with 500 m as the maximum) because of the relatively small size of San Francisco (46.8 mi^2) and because other studies have shown that coyote boldness and incidents are likely correlated with covariates that are at scales of ≤400 m (Farr et al., 2022). Additionally, because parks can potentially bias the representation of social-cultural covariates, all conflict-focused GLMMs were conducted on both the full geolocated dataset and on the subset of the geolocated records that occurred outside of parks.

Prior to conducting these analyses, we assessed collinearity among the covariates and found a very high degree of collinearity between wet season and dry season NDVI. Additionally, wet season NDVI had a marginally lower correlation with several other covariates compared to dry season NDVI. We thus used only wet season NDVI in our analyses. All other covariates had correlations of <0.5, with most <0.4 or lower (Figure S1). The highest degree of collinearity was between dry season NDVI and housing density (−0.416), and the lowest degree of collinearity was between wet season NDVI and pollution (0.002).

3 | RESULTS

3.1 | SFACC database overview

From January 2012 through June 2022, there were a total of 3904 unique coyote sighting records, providing a much more comprehensive dataset on San Francisco coyote sightings than any other (including iNaturalist, Figure S2). Of these, 3196 records contained descriptions of the encounter and/or comments from the reporting community member describing their concerns regarding coyotes. We were able to geolocate 78.8% of the records to exact points. For all years combined, confirmed conflicts comprised 15.6% of the records, records where the interaction type was unknown comprised 18.9% and non-conflicts comprised 65.5%.

3.2 | Sighting and conflict incidents over time and season

3.2.1 | Broad time scales and seasons

While there were fluctuations in proportions of reports constituting conflict across the 2012–2022 period (Figure 1a), there was a significant increase from 2017 to 2022 ($\beta=47.133$, $p<0.01$; Figure 1b).

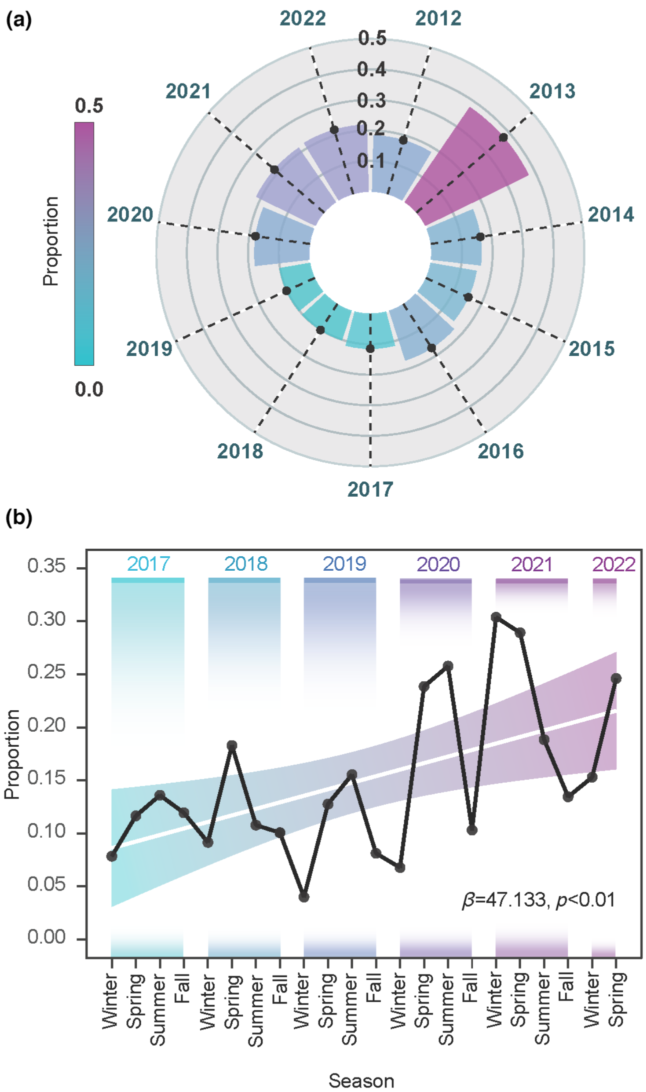

FIGURE 1 (a) the proportion of coyote sighting reports constituting a conflict interaction from 2012 to 2022, and (b) the proportion of coyote reports constituting human-coyote conflict from January 2017 to June 2022, across 3-month periods in San Francisco, California.

For all analyses concerning the binary time periods, the 2012–2022 and 2017–2022 analyses had comparable results; thus, we report on the results from the full dataset (2012–2022, Figure 2). The proportion of reports constituting conflict was higher during the COVID-19 pandemic (prop. = 0.212, $n=255$) than in the entire period prior (prop. = 0.128, $n=343$; $p<0.0001$; 95% CI = −0.111, −0.057), despite there being an overall decrease in number of sightings from 2019 ($n=676$) to 2020 ($n=285$). The proportion of reports constituting conflict was higher during the pup-rearing season (prop. = 0.212, $n=232$) than outside of the pup-rearing season (prop. = 0.132, $n=366$; $p<0.0001$; 95% CI = 0.053, 0.109). The proportion of reports constituting conflict was lower during the breeding season (prop. = 0.113, $n=131$) than outside of the breeding season (prop. = 0.175, $n=467$; $p<0.0001$; 95% CI = −0.086, −0.038). Finally, the proportion of reports constituting conflict was higher during the dry season (prop. = 0.184, $n=248$) than during the rainy season (prop. = 0.113, $n=131$; $p<0.0001$; 95% CI = −0.105, −0.043).

3.2.2 | Time of day

Of the total dataset, 66.3% ($n=2587$) contained a time of occurrence. At a fine temporal scale, the yearly temporal overlap (dhat1 or dhat4 depending on sample size) between conflict and non-conflict reports for the entire observation window (2012–2022) ranged from a low of dhat = 0.524 (in 2014) to high of dhat = 0.922 (2021) (Table S1). When comparing time of day of occurrence pre-COVID-19 versus during COVID-19, conflict reports for the two time periods had a lower temporal overlap (dhat4 = 0.792, 95% CI = 0.722–0.861) than non-conflict reports (dhat4 = 0.895, 95% CI = 0.859–0.932). Specifically, conflict reports during COVID-19 were reported more frequently during the day, rather than spiking around dawn as they did pre-COVID-19 (Figure S7). Meanwhile, when comparing recent years (2017–2022 grouped) to grouped prior years, there was a nearly significant difference in temporal overlap between conflict and non-conflict reports for each period. Specifically, the period comprising 2012–2016 had a temporal overlap of dhat4 = 0.801 (95% CI = 0.718–0.884) between conflict and non-conflict reports, and the period comprising 2017–2022 showed an increase, with a temporal overlap of dhat4 = 0.913 (95% CI = 0.874–0.952) between conflict and non-conflict reports (Figure 3). While the hours immediately after dawn continue to have the most conflict instances, both conflict and non-conflict have shifted over time to include more occurrences during midday relative to earlier years.

3.3 | Types of conflict reports

3.3.1 | General categories of conflict

Overall, conflict reports could be described as dog involved (77.9% of all conflict records), cat involved (7.7%), child involved (2.6%), adult involved (22.2%), vehicle involved (3.8%) and other (0.8%).

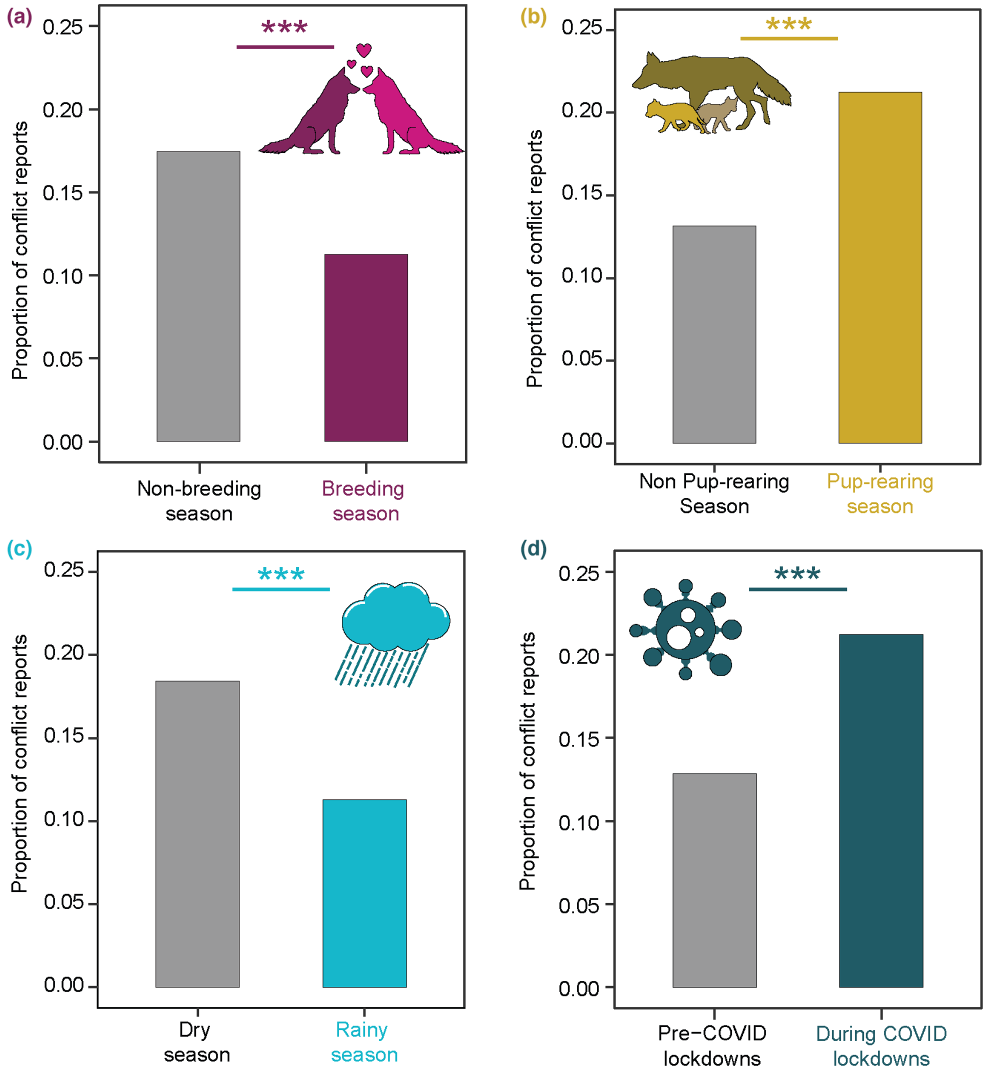

FIGURE 2 The proportion of San Francisco, California coyote sighting reports constituting conflict across the following binary time periods: (a) pup-rearing season versus not pup-rearing season, (b) breeding season versus not breeding season, (c) rainy season versus dry season, and (d) before the COVID-19 pandemic versus during the COVID-19 pandemic. For all comparisons $p<0.0001$.

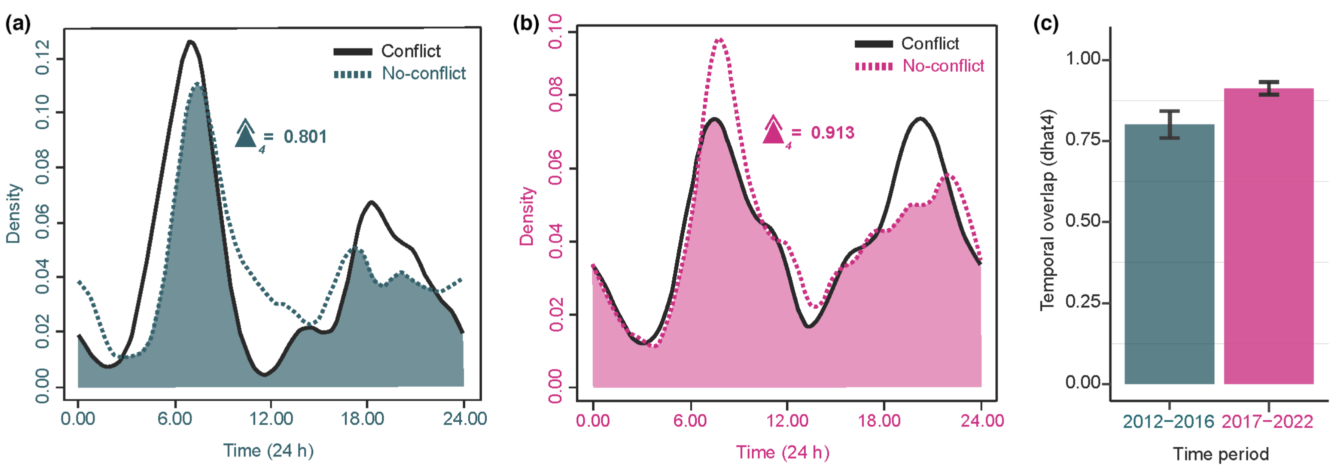

FIGURE 3 Temporal overlap (dhat4) between conflict and non-conflict reports in the periods comprising (a) 2012–2016 and (b) 2017–2022 in San Francisco, California, with (c) plot describing difference in temporal overlap including 95% confidence intervals derived from bootstrapped means.

TABLE 3 Summary of coyote conflict and non-conflict reports (2012–2022) in relation to dog involvement in San Francisco, California.

	Dog(s) involved	Unknown if dog(s) involved	Dog(s) not involved	Dog(s) on leash	Dog(s) off-leash	Unknown if on or off leash	Total reports
Conflict	474 (78.7% of total conflict reports)	24 (0.04%)	110 (18.1%)	254 (53.6% of dog-involved conflicts)	95 (20.3%)	119 (25.1%)	608
Non-conflict or unknown	438 (13.3% of total non-conflict reports)	1651 (50.1%)	1214 (36.8%)	214 (48.9% of dog-involved non-conflicts)	50 (11.4%)	175 (40%)	3296

When excluding conflict records found within parks, conflict reports ($n=350$) could be described as dog involved (71.4% of conflict records outside of parks), cat involved (12.9%), child involved (0.6%), adult involved (22.3%), vehicle involved (5.7%) and other (1.4%). Reports classified as "other" included coyotes eating irrigation infrastructure and coyotes eating chickens; notably, all occurred outside of parks. Over time, the yearly proportion of dog-related conflict has shown a slight increase, adult involved conflict has shown an increase and the other types of conflict have remained largely stable (Figure S3).

3.3.2 | Dog involvement

When compared to non-conflict reports involving dogs, conflict reports constituted a difference in proportion of 0.646 ($\chi^2=1190.6$, df = 1, $p<0.0001$, 95% CI = 0.608–0.678). Twenty percent of conflict reports involving dogs and 11% of non-conflict reports involving dogs reported the dog(s) being off-leash (Table 3).

3.3.3 | Additional characteristics of conflict and non-conflict reports

Across all conflict reports, 44.9% ($n=273$) of reports expressed that they and/or another person hazed the coyote(s) involved. Yet, the coyote departed in response to hazing in only 45.4% of these recorded hazing events. Notably, 229 of the reported hazing records were within conflict reports involving dogs. Hazing occurred in 4% ($n=134$) of non-conflict reports, with the coyote moving on in response to hazing in 64.9% of these events.

In 84% of conflict reports, the reporter mentioned the coyote's perceived bold behaviour (Figure S4), yet only 37.3% of reports noted aggressive behaviour (see Table 2 for behaviours). Meanwhile, 11.7% of reports mentioned coyotes getting bolder or more numerous or seeing coyotes more often than normal in a particular area. At last, 2.1% of conflict reports and 1% of non-conflict reports mentioned someone confirmed or likely intentionally feeding coyotes or feral cats.

3.4 | Attitudes toward and concerns about coyotes

3.4.1 | Attitudes overall

Regarding attitudes, 22.9% ($n=139$) of conflict reports expressed negative opinions toward coyotes, while 6.4% ($n=39$) expressed positive opinions toward coyotes. Nearly 4% ($n=131$) of non-conflict reports noted negative opinions toward coyotes, and, similarly, 3.9% ($n=128$) noted positive opinions toward coyotes. Reports of conflict were significantly more likely to express negative opinions toward coyotes than were non-conflict reports ($\chi^2=162.68$, df = 1, $p<0.0001$) and the opposite trend held true for positive opinions, but not to a significant degree ($\chi^2=3.5699$, df = 1, $p=0.059$). Nearly 7% ($n=40$) of conflict reports mentioned concern for coyote wellbeing. Notably, 35.9% of all reports that expressed a negative opinion also expressed a positive opinion and 5% also expressed concern for coyote well-being.

3.4.2 | Concerns about living with coyotes

Concern about living with coyotes was noted in 48.4% ($n=227$) of conflict reports, with 35% of these 227 reports also mentioning concern for coyote wellbeing, 59% noting positive opinions of coyotes and 97.84% noting negative opinions of coyotes. Reports of conflict were more likely than expected to express concern about living with coyotes, while non-conflict reports were less likely than expected to express concern about living with coyotes ($\chi^2=402.4$, df = 1, $p<0.0001$). Nearly 52% of people who had reported hazing during a conflict also noted negative opinions. However, for records for which the hazing was reported to be effective, only 16.55% of people noted negative opinions.

Of all conflict reports, 6.3% noted a concern for non-canine pet and livestock safety, 27.5% noted for dog safety, 5.1% noted for adult safety and 7.9% for child safety. Notably, across all reports (conflict and non-conflict), people who were concerned about dog safety were more likely to express negative opinions ($\chi^2=466.68$, df = 1, $p<0.0001$). This trend also held true for people who were concerned about child safety ($\chi^2=345.8$, df = 1, $p<0.0001$), people who were concerned about adult safety ($\chi^2=292.83$, df = 1, $p<0.0001$), and people who were concerned about non-dog pet safety ($\chi^2=155.16$, df = 1, $p<0.0001$). However, people who expressed concern for dog safety were also more likely than expected to express positive opinions ($\chi^2=30.278$, df = 1, $p<0.0001$), as were people who expressed concern for non-dog pet safety ($\chi^2=14.955$, df = 1, $p<0.001$).

Meanwhile, people who were concerned about non-dog pet safety were more likely than expected to also have reported a coyote conflict ($\chi^2=25.168$, df = 1, $p<0.0001$). The same held true for those concerned about dog safety, who were almost twice as likely than expected to have reported a coyote conflict ($\chi^2=201.48$, df = 1, $p<0.0001$).

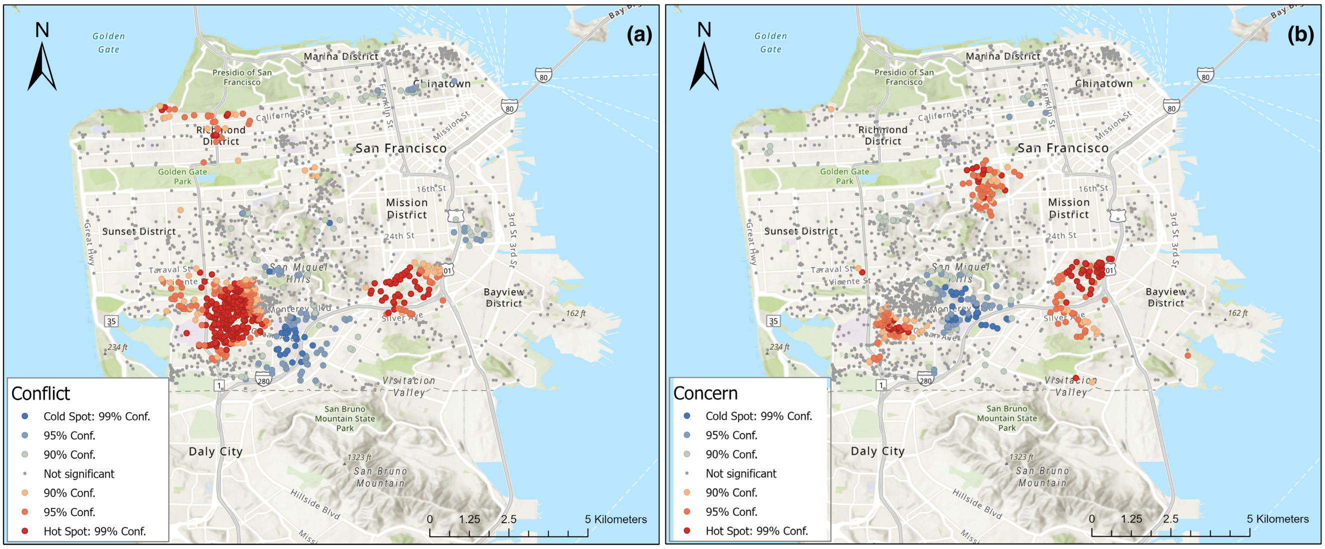

FIGURE 4 Results from Getis-Ord Gi* analysis of clustering of (a) conflict reports within all georeferenced coyote reports and (b) reported concern about coyotes in San Francisco, California, from January 2012 to June 2022.

Finally, people who reported conflict were more than three times as likely to express frustration with coyote management ($\chi^2=162.18$, df = 1, $p<0.0001$) and were nearly three times as likely than expected to be interested to learn more about coyotes ($\chi^2=235.15$, df = 1, $p<0.0001$) than people reporting non-conflict. People who reported conflict were also slightly more likely to express an understanding of coyotes and their ecology ($\chi^2=13.612$, df = 1, $p<0.001$).

3.5 | Sightings, conflict and attitudes in relation to spatial, sociocultural and ecological variables

3.5.1 | Local geospatial clustering characteristics

The Getis-Ord Gi* statistic for georeferenced reports revealed local hot spots and cold spots of conflict reports (Figure 4a), notably with some local hot spots and cold spots located nearly adjacent to each other. Local clustering of concerns regarding coyotes did not map directly onto conflict hot and cold spots but were dispersed across the city (Figure 4b). Additionally, reports in which coyotes were seen walking in the street or crossing the street (whether these involved conflicts or not), showed local hot spots in a northern, largely conflict-free, part of the city, and cold spots in a southern, largely conflict-prone, part of the city (Figure S5).

3.5.2 | Parks

Among conflict reports ($n=608$), 42.4% ($n=258$) occurred inside of parks. Of all geolocated reports ($n=3104$), 73.2% ($n=2271$) were located outside of parks, and 26.8% ($n=833$) were located inside of parks. Despite this, reported conflict was more likely to occur inside of parks ($\chi^2=64.285$, $p<0.0001$), with 31% of reports located inside of parks constituting conflict and 15.4% of reports located outside of parks constituting conflict. Additionally, 87.2% of dog-involved conflict reports took place within parks.

3.5.3 | Correlates of conflict reports and characteristics

When analysing correlates of conflict reports across all geolocated records at the point level (Figure 5, Figure S8), the best candidate model showed that conflict reports were more likely to occur in locations with higher NDVI ($\beta=0.202$, $p<0.001$), lower human population vulnerability ($\beta=0.\text{-}142$, $p<0.01$), higher pollution burden ($\beta=0.086$, $p<0.1$), and lower housing density ($\beta=-0.132$, $p<0.05$). Meanwhile, for geolocated records outside of parks, the best candidate model showed conflict reports were more likely to occur in locations with higher NDVI ($\beta=0.129$, $p<0.05$) and median income ($\beta=0.161$, $p<0.05$) (Figure S6). Results at the 100 and 500 m buffer level (for records outside of parks) were similar to the point level.

At last, when analysing correlates of hazing coyotes across point data outside of parks, median income ($\beta=0.229$, $p<0.01$) and NDVI ($\beta=0.177$, $p<0.01$) were positively correlated with hazing. This held true for the 500 m level. Yet at the 100 m buffer level, the best candidate model showed hazing was more likely to occur in locations with higher median income ($\beta=0.266$, $p<0.001$), lower housing density ($\beta=-0.248$, $p<0.01$) and lower population vulnerability ($\beta=0.134$, $p<0.05$).

3.5.4 | Correlates of attitudes and sighting characteristics

When analysing correlates of positive opinions toward coyotes across data outside of parks at the point level, no candidate models emerged. However, at both the 100 and 500 m buffer levels, positive

FIGURE 5 Geolocated coyote sighting reports from 2012 to 2022 in San Francisco, California, displayed across socioeconomic covariates, clockwise from top left: median income, pollution burden percentile, human population vulnerability characteristics percentile and housing density.

opinions were more likely to be expressed if the coyote interaction occurred in a location with lower population vulnerability (100 m: $\beta = -0.129$, $p < 0.05$; 500 m: $\beta = -0.171$, $p < 0.05$) and higher housing density (100 m: $\beta = 0.159$, $p < 0.05$; 500 m: $\beta = 0.255$, $p < 0.001$).

When analysing correlates of negative opinions toward coyotes across data outside of parks at the point level, negative opinions were more likely to be expressed if the coyote interaction occurred in a location with higher median income ($\beta = 0.178$, $p < 0.05$) and higher NDVI ($\beta = 0.151$, $p < 0.05$). At the 100 m buffer level, median income remained, but NDVI was not significantly correlated, and at the 500 m buffer level no correlates emerged. When analysing correlates of people's concern about coexisting with coyotes, there were no significant effects.

Notably, people were more likely to express that coyotes are becoming bolder or unusually more numerous in locations of higher housing density ($\beta = 0.163$, $p < 0.05$), pollution burden ($\beta = 0.238$, $p < 0.01$), and population vulnerability ($\beta = 0.218$, $p < 0.05$). Additionally, people were more likely to witness coyotes walking in the middle of or crossing streets in locations of lower NDVI ($\beta = -0.479$, $p < 0.0001$), higher road density ($\beta = 0.167$, $p < 0.01$), lower human population vulnerability ($\beta = -0.139$, $p < 0.05$) and higher housing density ($\beta = 0.121$, $p < 0.05$).

4 | DISCUSSION

Urbanisation continues to push humans and polarizing species like coyotes into resource-limited, shared space. Although positive to neutral interactions with coyotes were most common in our study, we found that negative interactions were also regularly reported and were associated with myriad societal and ecological factors in San Francisco. The regularity of these negative interactions between people and coyotes supports previous findings that the western USA has the highest concentration of cities prone to human-coyote conflicts (Poessel, Gese, et al., 2017). Our results point to a need to understand both the behaviour of conflict-prone species and human-wildlife conflict as complex social-ecological processes.

4.1 | Understanding social-ecological drivers of coyote behaviour

4.1.1 | Conflict as a function of coyote life histories and ecology

Three key social-ecological aspects—phenology, perceived threats and resource scarcity—emerged as the most influential contributors to conflict with humans in our region. First, consistent with our hypotheses, there were more conflict reports within the pup-rearing season, which aligns with existing work suggesting that conflicts (perceived or real) occur more often when coyote parents are protecting their young and/or escorting people away from their dens (Lukasik & Alexander, 2011). Second, most conflict reports (77.9%) involved a dog, and these interactions were disproportionately prevalent in reports located within parks. Coyotes may view domestic dogs as predators or competitors, thereby fostering opportunities for dog-involved conflicts. The proportionally high rate of dog-involved conflict in San Francisco aligns with previous research in which dog-related or pet-related conflict with coyotes was the most common (Frauenthal et al., 2017; Mowry et al., 2021; Poessel, Mock, et al., 2017). Third, there were proportionally more conflict reports occurring within rather than outside of parks, despite overall sightings being greater outside of the parks. Coyotes have been known to prioritise natural areas as substantial components of their home ranges (Mueller et al., 2018), and to prefer cover-rich habitats (Gosselink et al., 2003), which are largely confined to urban green spaces in San Francisco. Additionally, most coyotes in San Francisco den in and around the parks, which creates more propensity for perceived and realised conflict with people and off-leash dogs in those areas, particularly during pup-rearing season (see Farr et al., 2022; Schwartz, 2020). Finally, the yearly proportion of reports constituting conflict was highest in 2013, a historically dry year in the region (Swain et al., 2014) and within-year patterns matched this broader pattern, with conflict more prevalent during the dry season than in the rainy season. During times of resource scarcity, coyotes may venture into yards and green spaces with human-facilitated water sources and fruiting trees more frequently (Murray & St. Clair, 2017).

4.1.2 | Coyote behaviour as a function of human behaviour and the built environment

Urban coyote behaviour is intimately coupled with human behaviours, built infrastructure, and additional societal factors that shape resource distributions across the cityscape. In a review of carnivore attacks on people in developed countries, Penteriani et al. (2016) found that risk-enhancing human behaviour was involved in at least half of well-documented attacks. For coyotes, intentional or unintentional provisioning with anthropogenic food increases the likelihood of individuals to exhibit bold behaviours (Eapen, 2022; Timm & Baker, 2007). Our study corroborated this finding, as conflict reports were twice as likely to mention intentional feeding of coyotes and/or feral cats in or near the report location. In fact, there were several reports in which a person professed to routinely feeding a particular feral cat at or near their home prior to its predation; this type of food predictability could influence coyote behaviour in ways that engender conflict (Murray & St. Clair, 2017). Similarly, some residents reported hazing coyotes during interactions, but many others reported that they ran away from the coyote and/or hazed the coyote only until the animal stopped but had not moved away. Hazing is known to impact the behaviour of wild animals (Bonnell & Breck, 2017; Petracca et al., 2019), but the lack of widespread participation, incorrect delivery, and mixed cues of humans in cities who both haze and provision wildlife could have complex effects on the behaviour urban coyotes (Breck et al., 2017).

Urban landscape heterogeneity stemming from societal inequities undoubtedly influences the environmental conditions experienced by wildlife, thereby also influencing animal presence and behaviour (Caspi et al., 2022; Schell et al., 2020). For example, the luxury effect hypothesis (Leong et al., 2018) predicts that wealthier neighbourhoods tend to have a larger number, density, and ecological complexity of green spaces that are better equipped to harbour greater biodiversity. In contrast, more economically impoverished neighbourhoods chronically have reduced green space quantity and quality, with pollution and other ecological disturbances more intensified in these areas (Murray, Buckley, et al., 2022; Schell et al., 2020). In our study, higher median income and vegetation greenness were correlated with more conflict reports, which aligns with previous studies suggesting coyotes were more common in wealthier neighbourhoods (Magle et al., 2016, 2021; Wine et al., 2015). Interestingly, areas with higher pollution burdens and less green cover were associated with reports of less bold and more skittish coyotes, respectively, which suggest that ecological conditions detrimentally impacted by socioeconomic inequities are linked to wildlife behaviours. Coyotes that are compelled to move or disperse through llower quality urban spaces—with fewer places to hide and potentially more dangers—in search of preferred habitat may be pressed to reduce risky behaviours to improve their survival (Gese et al., 2012). Notably, pollution burden and greenspace availability are linked to societal wealth and systemic inequities (Murray, Buckley, et al., 2022; Schell et al., 2020); these disparities could have intersecting influences that shape coyote behaviours across the cityscape, such as differing access to and quality of municipal services (i.e. more trash, compost, and/or more rodents serving as attractants). Further research on the impact of urban structural inequities on animal behaviour will help identify the most salient social drivers moderating urban human-wildlife conflicts.

4.2 | Conflict is best understood from a social-ecological perspective

As outlined above, both the intrinsic biology of animals and the extrinsic social-ecological conditions animals experience influence their behaviour in cities. However, outcomes of human-wildlife interaction are not solely driven by animal behaviour; rather, conflict emerges based on how animal behaviour is perceived and interpreted by people, and these perceptions are informed by multifaceted aspects of human wellbeing, lived experience, and values regarding wildlife (Dickman, 2010). In our study, positive opinions about coyotes were correlated with lower human population vulnerability (inconsistent with our hypothesis) and higher housing density, while negative opinions were correlated with higher median income and higher NDVI (both consistent with our hypotheses). Coyotes are rarer in places of higher housing density due to their habitat needs (Magle, Simoni, et al., 2014), which could mean residents living in these areas have experienced fewer negative interactions with coyotes and therefore harbour more positive opinions overall. Additionally, people living in areas of lower human population vulnerability are likely socioeconomically advantaged, and thus may be more likely to have the time and means to both experience and report a range of interaction types with coyotes (Blake et al., 2020). To add complexity, there were significantly more negative opinions *and* positive opinions regarding coyotes expressed within conflict reports than non-conflict reports. In other words, a large proportion of people who expressed negative opinions also expressed positive opinions, and some people who expressed negative opinions also expressed a concern for coyote wellbeing. Although counterintuitive, and counter to our hypotheses, other results also suggest that interactions with coyotes are positively correlated with coexistence behaviours such as keeping pets inside, removing outdoor pet food and hazing (Lute et al., 2020). Together, these patterns demonstrate that a person's experiences with conflict do not necessarily mean that they have simplistic or reductionist views toward wildlife or conservation, or that they are unwilling to coexist (e.g. Basak et al., 2022; Don Carlos et al., 2009). On the contrary, instead of calling for lethal removal measures, those with more interactions may acclimate to the presence of wildlife (see Drake et al., 2021) and may be more willing to respond to coyotes with proactive and preventative actions that support coexistence (Lute et al., 2020).

Because interaction outcomes are moderated by human perceptions and attitudes, there can be a mismatch between perceptions of risk and the actual degree of risk in many human-wildlife conflicts (Dickman, 2010; Wilkinson et al., 2021). Notably, in San Francisco, local hot spots and cold spots of conflict do not always map directly onto hot spots and cold spots of people's concerns about coexisting with coyotes. This aligns with other studies that also note that interaction hot spots do not necessarily overlap with hot spots where people have heightened fear of coyotes (Lute et al., 2020). Such results indicate that the spatial factors facilitating conflict are not necessarily the same drivers of human concern. People's fear or awareness of risk can be elevated even without experiencing conflict themselves when instances of conflict take place in their communities or are disseminated and dramatised through social media and popular culture (Basak et al., 2022; Dickman et al., 2014).

4.3 | Implications

4.3.1 | The dynamism of human-wildlife conflict across San Francisco

Because reports of conflict, real or perceived, are defined from the perspective of the human participant, it follows that shifts in human behaviour can rapidly change the landscape of human-wildlife conflict. Perhaps the most salient example of this in our dataset is the effect of the COVID-19 pandemic on reported conflict. The proportion of conflict reports increased significantly during the COVID-19 pandemic (i.e. from the first lockdown measure in March 2020 onward) as compared to previous years. Furthermore, during the lockdown, conflict reports shifted to be more spread out across the day (as opposed to only at dawn and dusk). Although the coyotes' use of green space likely stayed the same, several factors, including San Francisco's temperate climate, the onset of work-from-home policies, and rapid growth in flexible-schedule gig and technology economies (Hathaway & Muro, 2016), seemed to have fueled an increase in park visitation, especially in the middle of the day (Venter et al., 2020). Such changes associated with lockdown subsequently increased the potential for both daytime wildlife sightings (Murray, Byers, et al., 2022). The shift in human behaviour to use parks more heavily throughout the day likely spurred the onset of a conflict scenario where it was previously absent, demonstrating that landscapes of human-wildlife conflict are dynamic and acutely responsive to shifts in human behaviours and environmental conditions.

Increases in extreme climate events (Abrahms, 2021) and urban development (Schell et al., 2020) alter the spatial distribution, temporal patterns (Gaynor et al., 2018) and behaviour of wild animals and people (Abrahms et al., 2023). Thus, as both humans and wildlife respond to social and environmental changes, human-wildlife conflict will be continuously reshaped over time and space. Researchers, managers and residents must therefore be equipped with knowledge of urban wildlife behaviour and adaptive management strategies that promote coexistence in urban spaces by not only mitigating ongoing conflicts and promoting positive interactions with wildlife but also predicting and preventing the emergence of conflict under future conditions. Our results suggest that the incredible response of human-coyote conflict to daily rhythms of city life will be exacerbated by rapid environmental changes generated by climatic, ecological, and social fluctuations.

4.3.2 | Suggestions for mitigating human-coyote conflict

Approaches to mitigating conflict should be two-pronged to address and respond to the confluence of coyote and human behaviours. Because coyote conflict reports correlate with higher vegetation greenness, and coyotes are more likely to den in vegetated areas (Raymond & St. Clair, 2023), managers should consider thinning vegetation in areas that would be particularly detrimental for coyotes to den, such as near dog play areas. Similarly, wildlife managers and community members could make off-leash dog areas and backyards less appealing to coyotes by focusing on implementing deterrents and removing attractants (e.g. securing trash bins, picking up fallen fruit; Grant et al., 2011; Murray et al., 2016). Additionally, a fairly low number of hazing events in non-conflict reports in our dataset suggests that people do not recognise that it is often appropriate to haze coyotes that approach people, even in less urgent situations (Schmidt & Timm, 2007; Timm et al., 2004). Accordingly, more broad-scale implementation of hazing efforts even in non-conflict interactions could assist in mediating urban coyote behaviour.

Regarding interventions targeting human behaviour and risk perceptions, it would be prudent for managers to explicitly target dog owners in educational campaigns centering coyote ecology, behaviour, dog safety, as most conflicts in the city involved dogs. Because the presence of anthropogenic attractants—such as garbage and outdoor cats—may negate the effects of community-level hazing for coyotes and other wildlife (Baker, 2007; Eapen, 2022; Sampson & Van Patter, 2020), researchers and managers should prioritise education efforts on reducing and securing attractants, as well as fostering comprehensive community science initiatives centered on mapping such attractants, determining their specific effects on human-wildlife interactions, and advocating for empirically informed, targeted mitigation. Our results suggest such education measures would be particularly important to promote within wealthier areas, where residents are most likely to report conflicts with coyotes. Furthermore, to determine within-city spatial and social-cultural heterogeneity in human-wildlife interactions, including human health and wellbeing, development and advertisement of community science reporting platforms should be carefully considered with the accessibility of diverse groups in mind (Davis et al., 2019; Hobbs & White, 2012; Merenlender et al., 2016; Ostermann-Miyashita et al., 2021; Woolley et al., 2021). For example, signage advertising how to report coyote sightings should be written in multiple languages and provide easy access to the online reporting form (i.e. via a prominent QR code). Signage also should not be limited to major green spaces where coyotes are known to den, but should instead be placed throughout the city. Educational efforts regarding coyote ecology and conflict prevention should also be standard in every school, and community members from across the city should be informed—through signage, community sessions, museum displays and so forth—on securing and reporting attractants. Lastly, empathetically engaging with people living alongside coyotes and valuing their experiences will provide meaningful avenues of connection that can enhance the success of coexistence strategies.

5 | STUDY LIMITATIONS

Because this dataset, like many other community monitoring efforts, was not collected with research as a goal, there are inherent biases within the dataset. Importantly, all conflict reports in this and other community-created datasets are underpinned by human perceptions, and thus influenced by the experiences, values and coyote-related knowledge of the reporter. Additionally, signage advertising the ability to report coyote sightings was initially unevenly distributed but improved over time, and there were more variations in information included in reports prior to the more standardised online reporting form. These can yield potential biases in who is reporting and why (see Quinn, 1995); for example, it is possible that the relative lack of reports from the eastern side of the city is due to biases in signage or ability to participate, rather than reflective of fewer coyotes. Additionally, pollution and vulnerability indices can serve as proxies for various other factors—such as variations in quality of municipal services (e.g. Brown, 1995; Ferronato & Torretta, 2019; Nygren, 2018; Williams & Collins, 2001), amount and types of anthropogenic attractants (Brown, 1995; Melosi, 2004) and a lack or lower quality of natural habitat (Cushing et al., 2015). While these two indices were not highly correlated with any of the other covariates in our study area, it is difficult to know exactly which factors (within the indices themselves, or within their proxies) may be influencing human-coyote interactions and attitudes.

6 | CONCLUSION

To promote coexistence between humans and wildlife in ever-expanding urban areas, it is imperative that we understand social-ecological contributors to positive and negative interactions with wildlife, especially those species typically perceived as a threat or nuisance to people. Using a community-curated, long-term dataset, we examined the spatial and temporal distribution of coyote reports in San Francisco, and how these reports relate to various sociocultural and ecological factors. We found that, fortunately, most coyote reports were unrelated to conflict, yet conflict reports have been significantly increasing over the past 5 years. Perceived conflict was linked to seasonal patterns of coyote behaviour and socioeconomic status of neighbourhoods, while also being strongly influenced by the presence of dogs. Conflict also appeared to fluctuate with annual climatic shifts and abrupt changes in human behaviour (i.e. the COVID-19 lockdown). We conclude that the dynamic landscape of realised and perceived human-coyote conflict in San Francisco is governed by interconnected societal and ecological factors that, albeit complex, may be predictable over space and time. Although our study is specific to the San Francisco Bay Area and limited by inherent biases associated with community-curated data, we expect that similar patterns of conflict and coexistence exist across other major cities. We therefore encourage managers and researchers to collectively explore similar contributing factors within their own cities, as well as coproduce and strengthen public education and management strategies that identify neighbourhoods and seasons where conflict is predicted to be highest.

AUTHOR CONTRIBUTIONS

Christine E. Wilkinson and Tal Caspi conceived the ideas. Christine E. Wilkinson and Christopher J. Schell designed the methodology. Tal Caspi and Deb Campbell coordinated much of the investigation, which was aided by Christine E. Wilkinson, and also provided resources. Christine E. Wilkinson led the analyses and visualisations, which were aided by Christopher J. Schell. Christine E. Wilkinson led the writing, which was aided by Tal Caspi and Lauren A. Stanton. All authors discussed, edited and approved the final version.

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CONFLICT OF INTEREST STATEMENT

The researchers declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data used for this study are publicly available through the San Francisco Sunshine Ordinance (Chapter 67: The San Francisco Sunshine Ordinance of 1999) and the full dataset may be gained upon request from San Francisco Animal Care and Control. The cleaned, coded and anonymised version of the data used for this study can be found here: https://doi.org/10.5061/dryad.34tmpg4rf.

ORCID

Christine E. Wilkinson https://orcid.org/0000-0001-5462-0086
Christopher J. Schell https://orcid.org/0000-0002-2073-9852

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SUPPORTING INFORMATION

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

Table S1. Temporal overlap coefficients (dhat1 and dhat4, dependent on sample size) between conflict and non-conflict records for each year and for all years combined, including bootstrapped means (10,000 resamples), standard deviation, and 95% confidence intervals.

Figure S1. Correlation plot for covariates initially considered. Population density and dry season NDVI were excluded from analyses.

Figure S2. (A) Georeferenced records from San Francisco Animal Care and Control coyote sightings database 2012–2022 [$n=3111$] and (B) research-grade coyote sighting records from iNaturalist 2012–2022 [$n=2099$].

Figure S3. Yearly proportions of conflict reports constituting specific types of conflict: adult involved, cat involved, child involved, dog involved, vehicle involved, and other. "Other" includes reports of coyotes chewing on irrigation and eating chickens.

Figure S4. Yearly proportions of conflict reports constituting specific characteristics describing the human-coyote interaction(s): bold coyote behavior, aggressive coyote behavior, coyote was hazed, and coyote was eating/biting or attempting to eat/bite human attractants.

Figure S5. Results from Getis-Ord Gi* analysis of coyote sighting records in which coyotes were seen walking in or crossing the street, versus records in which they were not seen doing so (from all georeferenced reports January 2012 to June 2022).

Figure S6. Odds ratios and confidence intervals for the top-performing point-level generalized linear mixed models for conflict, including the full dataset and the subset of the data located outside of parks.

Figure S7. Temporal overlap of non-conflict reports pre-COVID and during COVID, and temporal overlap of conflict reports pre-COVID and during COVID.

Figure S8. Georeferenced submissions to the SFACC coyote sighting database from January 2012 to June 2022, including symbology for whether a sighting was classified as a conflict occurrence.

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