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Research Article

Modeling urban socio-ecological drivers of human–carnivore coexistence

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Abstract

Achieving human–carnivore coexistence is a growing challenge in an increasingly crowded world. In many cases, humans are already sharing landscapes with carnivores, but conditions promoting coexistence are not well understood. Coyotes (*Canis latrans*) are adaptable meso carnivores and their activities increasingly overlap with those of humans in urban environments. Does this overlap constitute coexistence? How do social variables situated within their rightful ecological contexts influence the potential for conflict? In this study, we explore aggregated social and land cover variables contributing to coexistence between humans and coyotes. We surveyed residents in four North Carolina cities on their perceptions, interactions and preferred management actions related to coyotes. We then modeled spatial patterns in urbanite interactions with and perceptions regarding coyotes and investigated how land cover characteristics may correlate with those perceptions. Our results suggest prior interactions and select land cover types may drive human coexistence with coyotes and contribute contextual understanding of urban socio-ecological systems to prevent conflict and effectively promote coexistence. Additional research that expands upon this study and explores spatial as well as temporal dimensions of human–wildlife coexistence is needed in diverse contexts.

Key words: *Canis latrans*, carnivores, environmental attitudes, human–wildlife conflict, socio-ecological systems

Introduction

As the influence of humans increasingly permeates the globe, the question of how humans can coexist with carnivores grows more important. Human-dominated landscapes can provide critical habitat for carnivores, who in turn provide benefits and present risks to humans that share those landscapes. A particularly vexing challenge for humans living in the increasingly crowded world of the Anthropocene is identifying conditions that foster coexistence between us and carnivores (Friedman 2008; Gehrt, Riley, and Cypher 2010). Human perceptions of, e.g. risk and behaviors, such as feeding wildlife, can undermine the conditions necessary for coexistence and increase the chances of conflict (Gore et al. 2008; Zajac et al. 2012; Lute and Gore 2019). Land sharing and land sparing (i.e. setting aside protected habitat for wildlife) can occur virtually anywhere and anytime, including in urban areas (Gehrt, Anchor, and White 2009; Kertson et al. 2011). Carnivores are increasingly ranging into urban spaces and there is much to learn about what variables promote coexistence between humans and carnivores in urban areas. Full understandings of the circumstances, challenges, opportunities and knowledge of urban system dynamics are required to reveal the conditions by which coexistence is sustainably maintained (Burdett et al. 2010; Bateman and Fleming 2012; Kertson, Spencer, and Grue 2013).

The study of novel carnivores (i.e. those new to a human settlement or returning to a now human-dominated landscape after extirpation projects) residing in urban systems is an emerging area of study that is necessary for understanding obstacles to coexistence. Coyotes (*Canis latrans*) are an excellent example of a novel carnivore that have adapted to urban landscapes. As they have expanded into urban environments, their niches have often overlapped with that of humans in thoroughly modern ways. These overlaps between humans and coyotes are recurrently captured by local media coverage of, e.g. MAX Light Rail-riding coyote (Sallinger 2011), a coyote on the rooftop of a bar in New York City (Bittell 2015) or coyotes living peaceably within the boundaries of an international airport (Gehrt, Anchor, and White 2009). These depictions highlight spatial and temporal components that are often overlooked by researchers but may provide clues to conceptualizing modern notions of coexistence. To paint a more accurate picture, we need to consider how social, wildlife and natural subsystems interact and how these interactions evolve across time and space.

Within the social subsystem and abiding by the widely accepted cognitive hierarchy, human attitudes toward coyotes influence behaviors that determine whether humans and coyotes can share space. Attitudes have evolved over time and coyotes have expanded their range. Over 30 years ago, coyotes were among the least liked animals in North America (Kellert 1985). As with many carnivore species, contemporary attitudes have become more favorable toward coyotes (Stevens, More, and Glass 1994; Vaske and Needham 2007; Jackman and Rutberg 2015). Ambivalence is still common, however (Elliot, Vallance, and Molles 2016), especially in locales where negative human–coyote interactions have been publicized (Sponarski et al. 2015, 2016; Frank et al. 2016). Attitudes with respect to risk are particularly influential in areas where coyotes are newly established, such as on the east coast of the USA. How a person's values are oriented towards wildlife (Elliot, Vallance, and Molles 2016; Lu et al. 2016; Sponarski et al. 2016), emotions, and social identities are critical variables that influence the formulation of risk perceptions. In aggregate, they are powerful predictors of support for coyote management strategies (Sponarskiet al. 2015; Drake et al. 2019; Drake et al. 2020).

Interactions between natural, wildlife and social subsystem variables can influence the likelihood that humans and carnivores can share space. Yet, these variables are often not adequately incorporated into holistic, system models of human–carnivore coexistence (Supplementary Fig. S1; Lischka et al. 2018). Coyote and human subsystems interact in multiple domains, but perhaps most obviously in shared use of landscapes. Each species' movements through a landscape and, thereby, persistence, will influence the likelihood and nature of interactions. Humans and coyotes may both use open spaces in urban areas, but humans are more likely to encounter coyotes in medium-level development areas, because low development promotes avoidance behavior among coyotes, and high development may discourage coyote presence (Poessel, 2015). Research suggests that land cover may moderate species persistence and, therefore, encounters between humans and carnivores (e.g. Dellinger et al. 2013). Thick vegetation can create a surprise scenario for both species whereas open space creates long sight lines and more frequent interactions at similar population densities. These experiences are often indelible for both species and how each reacts within different land cover types may help reveal under what conditions coexistence is feasible.

To inform discussions about what conditions are necessary to achieve human–carnivore coexistence, this study explores the association between land cover and human perceptions and behaviors concerning coyotes across urban areas. We surveyed residents in four cities in North Carolina, USA, and conducted social-spatial analyses. This work builds upon past research that identified attitudinal differences among residents of North Carolina cities and suggested broader patterns in social identity may explain individual perceptions of coyotes and management preferences (e.g. when lethal control was deemed acceptable; Drake et al. 2019). We build on that knowledge base to test social and land cover predictors of coexistence and their spatial variation.

Study area

Coyotes expanded from their original range in the Great Plains and western North America and established residency in the southeastern part of the country during the late 20th Century (Gompper 2002). They now reside in all major metropolitan areas of North Carolina (Poessel, Gese, and Young, 2017). Their ability to live in close proximity to highly dense populations of humans is credited to their behavioral plasticity, fission–fusion social structure, extirpation of larger predators and high fecundity in response to mortality, including anthropogenic mortality (Knowlton 1972; Kilgo et al. 2017). Research on urban coyote populations across the USA suggests that coyotes can thrive in urban areas with open space, natural cover and an adequate prey base (Bekoff and Gese 2003; Gehrt 2007; Gehrt, Anchor, and White 2009; Gehrt, Brown, and Anchor 2011).

We surveyed residents of four metro areas, ranging across three of North Carolina's ecosystems. Based on 2016 land cover data, Asheville is located in North Carolina's Mountains region and has a relatively high amount of open space and forest cover compared with the other three cities in our study. Asheville's economy increasingly relies on nature-based tourism and recreation (Strom and Kerstein 2015) and prior analyses suggest a nature-oriented identity that tolerates coyotes is common among city residents (Drake et al. 2019).

Charlotte is the largest city in North Carolina and located in the Piedmont region, along with the Triangle Area cities Raleigh and Durham (i.e. Raleigh–Durham). Comparatively, Charlotte has less forest and agricultural land cover than Asheville, Raleigh–Durham and Greenville, reflective of the city's size, urbanity and commercial focus (US Bureau of Labor Statistics 2016). The Raleigh–Durham area has less open space and agricultural land cover than the other cities in our study. Its focus is on professional, technical and educational services (US Bureau of Labor Statistics 2016).

Greenville is in the Coastal Plains region of North Carolina and only slightly larger population than Asheville with high percentages of open space, forest and agricultural land cover. Its economy and identity are more working class than the other cities in this study, with manufacturing and health care its top industries (US Bureau of Labor Statistics 2016). Greenville also has the highest poverty rate and lowest formal education rate among the cities in our study.

Methods

Survey instrument

The survey instrument was developed based on expert elicitation from the North Carolina Wildlife Resources Commission biologists and pretested with a mailing to 300 urban residents distributed evenly across the four cities. We adapted the mail survey and repeated the same process for the greenway intercept survey (see Supplementary Materials). The Human Subjects Internal Review Board of North Carolina State University approved all survey protocols (protocol No. 5798).

The survey included close-ended questions with 1–5 Likert-type response options on a range of subjects related to coyotes, including four 'human–coyote interactions' [i.e. coyotes (i) seen or (ii) heard in proximity to the home, interactions with coyotes that felt threatening to (iii) people or (iv) companion animals]. We explored four sets of dependent variables in depth, developing our variables by calculating the composite mean. We measured 'support for coyotes' with 12 statements to gauge support, enjoyment and importance of wild coyotes living in the state, city or neighborhood and near residences. Four statements comprised our measure of human tolerance for coyotes (e.g. tolerating coyotes would be acceptable/unacceptable in the metro area/neighborhood). We measured 'risk perception' by measuring concern using five scenarios (i.e. coyotes attacking children/pets, near home, causing damage to property, spreading rabies). We characterized 'lethal acceptability' by recording preferences for lethally removing coyotes in seven different scenarios (i.e. coyotes living in the metro area/neighborhood, approaching a person, threatening a pet; wildlife officials shooting/trapping coyotes; and paying private contractors to trap). We captured 'coexistence behaviors' by calculating the aggregate mean response concerning the implementation of three self-reported actions (i.e. kept pets inside, removed outside pet food and supervised outdoor pets) in response to actual occurrences of perceived problems with coyotes near the respondent's home. The survey concluded with seven demographic measures (i.e. age, sex, formal education, ethnicity, income, companion animals in the household and the size of the respondent's home town).

Urban mail survey

Survey Sampling, Inc. (Fairfield, CT, USA) provided the sampling frame for residents based on drivers' licenses, property records and landline and cell phone registries to achieve an ~76% coverage representative of the four metropolitan areas. Using the tailored design method (Dillman et al. 2009), 1400 randomly selected residents from each city were contacted via mail four times over a 5-week period between July and August 2015 deploying the following: (i) letter of intent; (ii) survey packet consisting of cover letter, informed consent letter, survey booklet and self-addressed return envelope; (iii) reminder postcard; and (iv) final survey packet.

Our response rate was 15.5% ($n = 856$, with 89 undeliverable surveys). We measured non-response bias using Chi-square tests of independence and one sample t-test to compare four demographic characteristics (i.e. gender, ethnicity, education and age) with 2014 American Community Survey 5-year estimates for each city (US Census Bureau 2014). When compared with census estimates, survey respondents were skewed male ($X^2 = 20.2$, $P < 0.001$), older ($t = 12.2$, $P < 0.001$), more educated ($X^2 = 256.3$, $P < 0.001$) and more likely to be Caucasian ($X^2 = 209.7$, $P < 0.001$). These biases are typical for mail surveys (Bell, Huber, and Viscusi 2011; Ansolabehere and Schaffner 2014). Mirroring similar studies, this survey experienced the linear decline in response rates that mail surveys have increasingly experienced over time (Stedman et al. 2019).

Greenway intercept survey

Between 2 and 10 July 2016, we conducted an intercept survey (total $n = 402$) on four greenways within Charlotte's city limits: Little Sugar Creek ($n = 152$), Upper McAlpine ($n = 100$), McMullen/Lower McAlpine ($n = 100$) and Irwin Creek ($n = 50$). Two project members located high traffic areas along each greenway within 1 km of a trailhead or parking lot and contacted every third adult greenway user that passed by on foot. We divided our survey effort evenly throughout the day (8:00–19:00), and 70.5% of the 570 greenway users we contacted agreed to take the survey. We presented respondents with paper copies of the survey instrument in which questions about coyotes at the household or neighborhood level were changed to be at the 'greenway' level (i.e. 'On a greenway and in the last 12 months, how many times have you heard a coyote?').

Land use and land cover

Spatial land cover data were obtained from the US Geological Survey's (2019) 2016 National Land Cover Database. The 15 land cover classes explored were: Open Water, Developed-Open Space, Developed-Low Intensity, Developed-Medium Intensity, Developed-High Intensity, Barren Land, Deciduous Forest, Evergreen Forest, Mixed Forest, Scrub/Shrub, Grassland/Herbaceous, Pasture/Hay, Cultivated Crops, Woody Wetlands and Emergent Herbaceous Wetlands. Spatial ZIP code polygon data were obtained from 2010 US Census Bureau (2015). Raster land cover data were matched to survey data that included ZIP codes, using Environmental Systems Research Institute's (ESRI) ArcGIS Desktop 10.5.1 software suite. Each ZIP code polygon for the study area was converted to a raster layer and each raster was then used as a mask to extract the corresponding land cover classification. We used the Python 2.7 programming language in ArcGIS to access the contents of each raster's attribute table to determine pixel counts (30×30 m) corresponding to each land cover class in the ZIP code. The information for each ZIP code was arranged in a line of comma separated text before being written out to a single text file. We then merged land cover data into survey data by matching ZIP codes variables in STATA 13.1 (StataCorp, TX, USA).

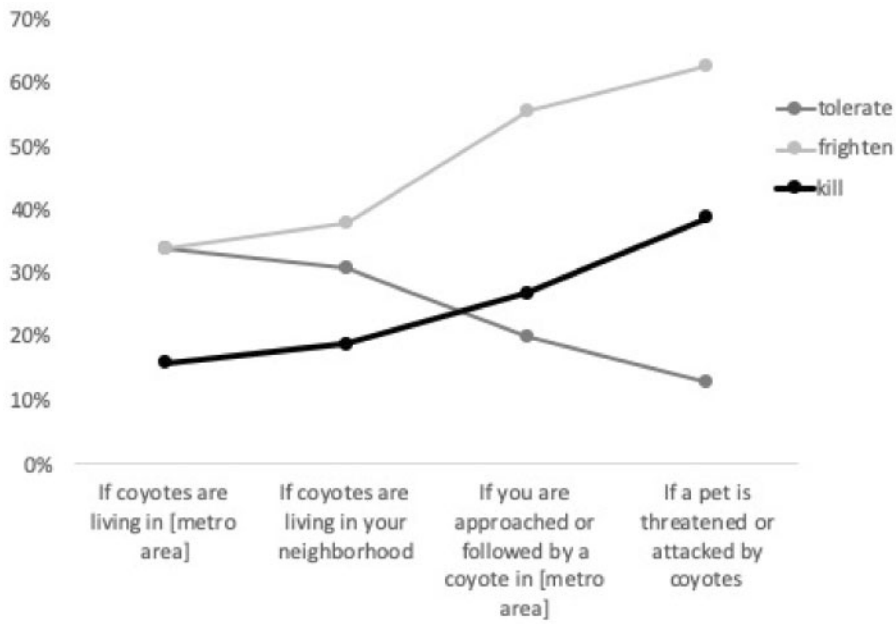

Figure 1: Tolerance for coyotes. The acceptability of tolerating wild coyotes decreased as the proximity became closer to the respondents' homes or increased in severity. Frightening coyotes was the preferred response to most interactions and tied with tolerance when coyotes were simply living in the respondent's metropolitan area.

The same process was used for greenway data, with the additional step of creating a polygon to function as a replacement to ZIP codes. Polygons were created by buffering the greenway with a radius of 2548 m, which corresponds to an area of 20.43 km^2 and the average coyote home range size in North Carolina (Young and Malpeli, 2015). Thus, any spot along the greenway was buffered by a home range size area. Surveyed greenways were digitized and saved to .kmz format in Google Earth 7.3.2.5776 (64-bit). We used ArcGIS to convert .kmz format to ESRI proprietary shapefile format for analysis of environmental variables.

Analysis

We calculated attitudinal descriptive statistics and created mean scores for four variables that met standards for scale reliability (Cronbach, 1951): 'support for coyotes' (Cronbach's $\alpha = 0.94$), 'risk perception' (Cronbach's $\alpha = 0.92$), 'lethal acceptability' (Cronbach's $\alpha = 0.92$) and 'coexistence behaviors' (Cronbach's $\alpha = 0.83$) in STATA. We combined mail and greenway intercept surveys and tested these data together. Using an exploratory approach to identify potential predictors of coexistence (Ullman, 2006), we examined Spearman correlations between ranked ordinal and continuous variables: the four aforementioned composite variables, measures of 'human–coyote interactions', and the 14 land cover classes. Our interest was not to measure individual characteristics of the respondent (see Drake et al. 2019 for those results) but to ground conflict and coexistence in broader socio-ecological contexts. Thus, we considered land cover as independent variables that would potentially influence encounter rates and, following the cognitive hierarchy, would then influence human understandings (i.e. perceptions) and then behaviors. Theorizing a stepwise and path dependent process to achieving coexistence, we tested the most parsimonious structural equation model (SEM) that included variables found to have significant correlations ($P < 0.01$) using the sembuilder command (Supplementary Tables S1, S2 and Fig. 2).

To map localized clusters of survey responses to identify potential hot spots for conflict or coexistence, we first geocoded the survey responses based on respondents' addresses and then implemented the Getis-Ord Gi* statistic available in the Spatial Statistics toolbox in ArcMap. The Gi* statistic identifies hot spots in a spatial dataset by examining each feature (i.e. survey response at a specific location) within the context of neighboring features to determine if high values are surrounded by high values (hot spot) or if low values are surrounded by low values (cold spot). The Gi* statistic is a z-score where more intense clustering of high values is associated with larger positive z-scores and more intense clustering of low values are associated with negative z-scores. Since the test requires specification of how the spatial relationships among neighbors are defined, we used incremental spatial autocorrelation (ISA) to determine the fixed distance band. This method measures spatial autocorrelation for a series of distances and returns a z-score that indicates where spatial processes that contribute to clustering are most pronounced. We used the distance associated with the first statistically significant ISA z-score (1.96) for each variable in the analysis. If no peak values occurred that helped identify distances where clustering was most pronounced, we used a distance threshold that ensured every feature has at least one neighbor. We focused on and present the spatial analysis for all types of 'human–coyote interactions', 'risk perception' and 'coexistence behaviors' based on the above hypothesized model (e.g. interactions influence risk perceptions which in turn dictate coexistence behaviors). Prior research suggests such relationships are strong (Gore et al. 2008; Zajac et al. 2012; Lute 2014; Lute and Gore 2019).

Results

Perceptions of and interactions with coyotes

The general public had generally neutral attitudes toward coyotes. 'Support for coyotes' averaged 2.6–2.8 across the four cities

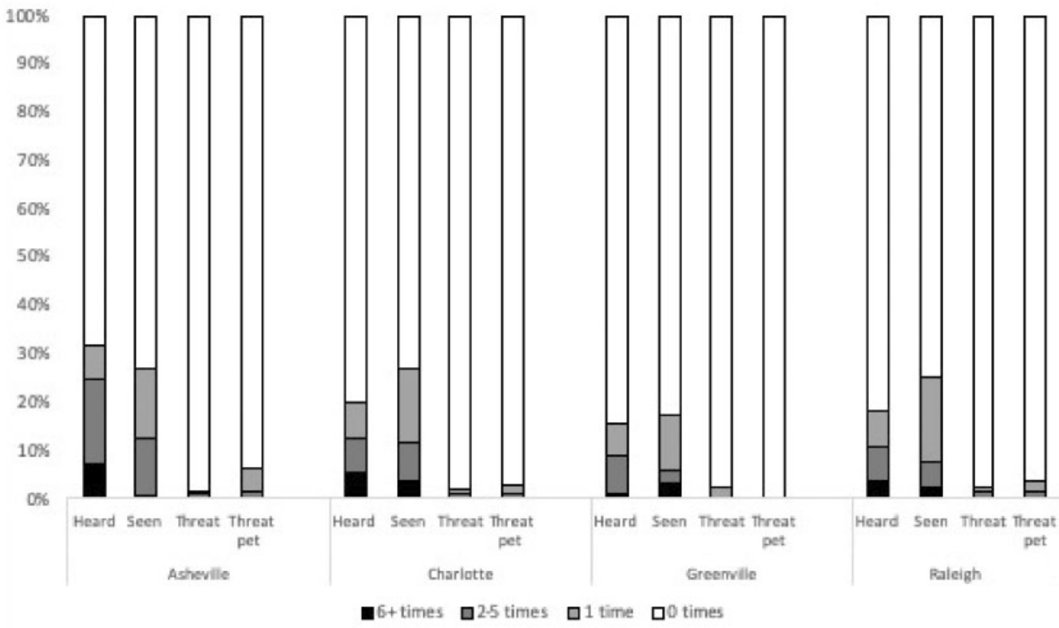

Figure 2: Frequency of human–coyotes interactions. The majority of respondents in each city had no interaction with coyotes. Coyotes were reportedly seen more than heard in Charlotte and Raleigh–Durham. Coyotes were reported to threatened companion animals more than people in Asheville.

(response options ranged from 1 to 5, range of SD = 0.95–1.10). 'Tolerance' for wild coyotes on the landscape decreased as the scenario became closer to respondents' homes, and frightening coyotes was consistently a more acceptable response than killing them (Fig. 1).

'Risk perception' across cities averaged 2.0–2.5 (SD = 1.08–1.25), corresponding to low concern. Among all respondents, highest concern was for coyotes spreading rabies ($M = 2.83 \pm 1.51$) and attacking pets (2.70 ± 1.45).

'Lethal acceptability' was moderate, averaging 2.5–2.8 across the four cities (SD = 1.18–1.30). Respondents slightly preferred wildlife officials trapping and euthanizing coyotes ($M = 2.87 \pm 1.36$) more than private trapping ($M = 2.37 \pm 1.36$) or wildlife officials shooting ($M = 2.57 \pm 1.41$).

'Interactions with coyotes' were infrequent in all cities (Fig. 2). Asheville respondents reported they had higher encounter rates for hearing and having companion animals threatened by coyotes per capita. Seeing coyotes occurred at equal rates in Asheville, Charlotte and Raleigh–Durham. Charlotte and Raleigh–Durham respondents reported seeing coyotes at higher frequencies than hearing them.

'Coexistence behaviors' were common among respondents who acted in response to a perceived problem with coyotes. Among our sample, 70 respondents acted in response to the presence of coyotes. The most frequent responses were behaviors that allowed for mitigation of conflict and coexistence with coyotes: kept pets inside ($n = 56$), supervised outdoor pets ($n = 43$) and removed outside pet food ($n = 38$). People also yelled at or scared coyotes ($n = 38$), called wildlife officials ($n = 17$) and few actually shot at a coyote ($n = 13$). In terms of perceived effectiveness, shooting coyotes was ranked highest at 77%, followed by keeping pets inside (61%), supervising outdoor pets (58%), removing outside pet food (55%) and yelling at or scaring coyotes (47%). Most respondents did not believe calling wildlife officials was effective (35% agreement that the action solved the problem).

Socio-ecological relationships and predictors of coexistence

To explore potential predictors of 'interactions with coyotes', we ran correlations with 14 land cover classes. The four types of interaction with coyotes were positively correlated with each other and all interactions positively correlated with putting food out for non-avian wild animals (for all results see Supplementary Table S1). Open space and pasture were positively correlated with hearing coyotes (respectively, $r = 0.13$ and 0.16, both $P < 0.001$) and experiencing an interaction that felt threatening to the respondent (open space $r = 0.14$, $P < 0.001$; pasture $r = 0.08$, $P < 0.05$) or companion animals (open space $r = 0.10$ and pasture $r = 0.08$, both $P < 0.01$). Deciduous forest was positively correlated with three interaction types (heard $r = 0.20$, seen $r = 0.13$ and pets threatened $r = 0.12$, all $P < 0.001$) as was mixed forest (heard $r = 0.15$, $P < 0.001$; seen $r = 0.09$ and pets threatened $r = 0.08$, both $P < 0.05$). Low development was positively correlated with experiencing an interaction that felt threatening ($r = 0.10$, $P < 0.01$). Pasture was positively correlated with all interaction types (heard $r = 0.16$, $P < 0.001$; seen $r = 0.11$, $P < 0.01$; respondent felt threatened $r = 0.08$, $P < 0.05$; pets threatened $r = 0.10$, all $P < 0.01$).

To explore potential predictors of 'risk perception', 'lethal acceptability' and 'coexistence behaviors', we analyzed correlations with 'support of coyotes', four categories of 'interactions with coyotes', and the 14 land cover classes. 'Support for coyotes' was negatively correlated with the respondents feeling threatened ($r = -0.22$, $P < 0.05$; Supplementary Table S2). 'Lethal acceptability' was negatively correlated with 'support for coyotes' ($r = -0.61$, $P < 0.001$) and positively correlated with seeing them ($r = 0.26$, $P < 0.05$). 'Risk perception' was negatively correlated with 'support for coyotes' ($r = -0.54$, $P < 0.001$) and positively correlated with 'lethal acceptability' ($r = 0.42$, $p < 0.001$) and respondents feeling threatened ($r = 0.31$, $P < 0.01$). 'Coexistence behaviors' were negatively correlated with

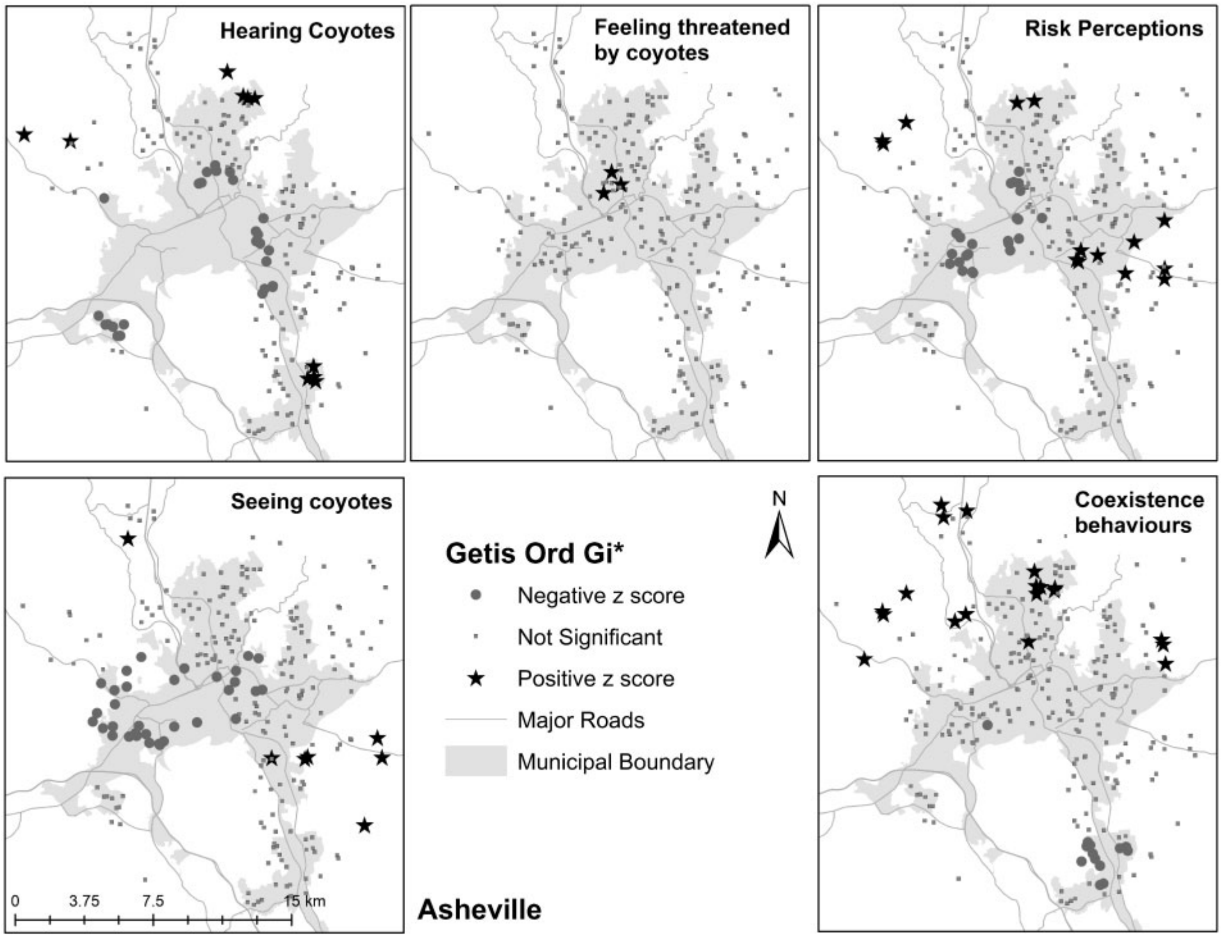

Figure 3: Asheville hot spot analysis for coyote interactions, risk perception and coexistence behaviors. For statistically significant positive z-scores (denoted by stars), the larger the z-score is, the more intense the clustering of high values (i.e. hot spot). For statistically significant negative z-scores (denoted by larger circles), the smaller the z-score is, the more intense the clustering of low values (i.e. cold spot). Clustering for interaction types was inconsistent. Risk perception were highest in the north and east peripheries. Coexistence behaviors clustered in the north side of the city and were significantly lower in the southern neighborhood.

'lethal acceptability' ($r = -0.20$, $P < 0.05$) and positively correlated with three interactions (heard $r = 0.29$, $P < 0.01$; respondent felt threatened $r = 0.29$, $P < 0.01$; pets threatened $r = 0.21$, $P < 0.05$).

Consistently significant predictors in the above correlations suggest the most parsimonious SEMs comprise the following: (i) deciduous and mixed forest, pasture and open space regressed on hearing coyotes; (ii) open space and herbaceous land cover regressed on feeling threatened by coyotes; and (iii) both interaction types regressed on 'coexistence behaviors' (Supplementary Fig. S2). The SEM revealed significant relationships between deciduous forest on hearing coyotes, open space on feeling threatened by coyotes and both interactions on 'coexistence behaviors' (all $P < 0.001$).

Hotspots for four North Carolina cities

Spatial Getis Ord Gi* analyses of variables across all cities indicated the majority of data features returned a non-significant z-score ($\alpha = 0.10$), which indicates that the response for that feature is different than neighboring responses. In other words, data points classified as not significant do not exhibit local spatial autocorrelation. However, significant Gi* statistics did reveal heterogeneity in interactions, 'risk perception' and 'coexistence behaviors' within each city (Figs 3–6). General patterns across cities suggest that higher interaction rates, 'risk perception' and 'coexistence behaviors' occur at the peripheries or outside metropolitan areas but respondents who felt threatened by coyotes were located in different areas than those who saw or heard coyotes or had higher risk perceptions. Higher positive clustering (i.e. hot spots) of all variables occurred in Asheville (Fig. 3) compared with the other cities. In Asheville and Charlotte, 'coexistence behaviors' were more common on the north side of the city. However, in Charlotte, results suggest more intense clustering of low values (i.e. cold spots) than the clustering of high values (Fig. 4). Greenville results also showed more cold spots than hot spots for interactions with coyotes and 'risk perception' (Fig. 5). 'Risk perception' generally overlapped spatially with all types of interactions. 'Coexistence behaviors' revealed no discernible patterns, perhaps due to low participation in such behaviors in the first place. Raleigh–Durham showed cold spots for hearing coyotes near the home and 'risk perception' (Fig. 6).

Discussion

Human–coyote interactions, even negative ones, may promote coexistence behaviors for several reasons. Although previous

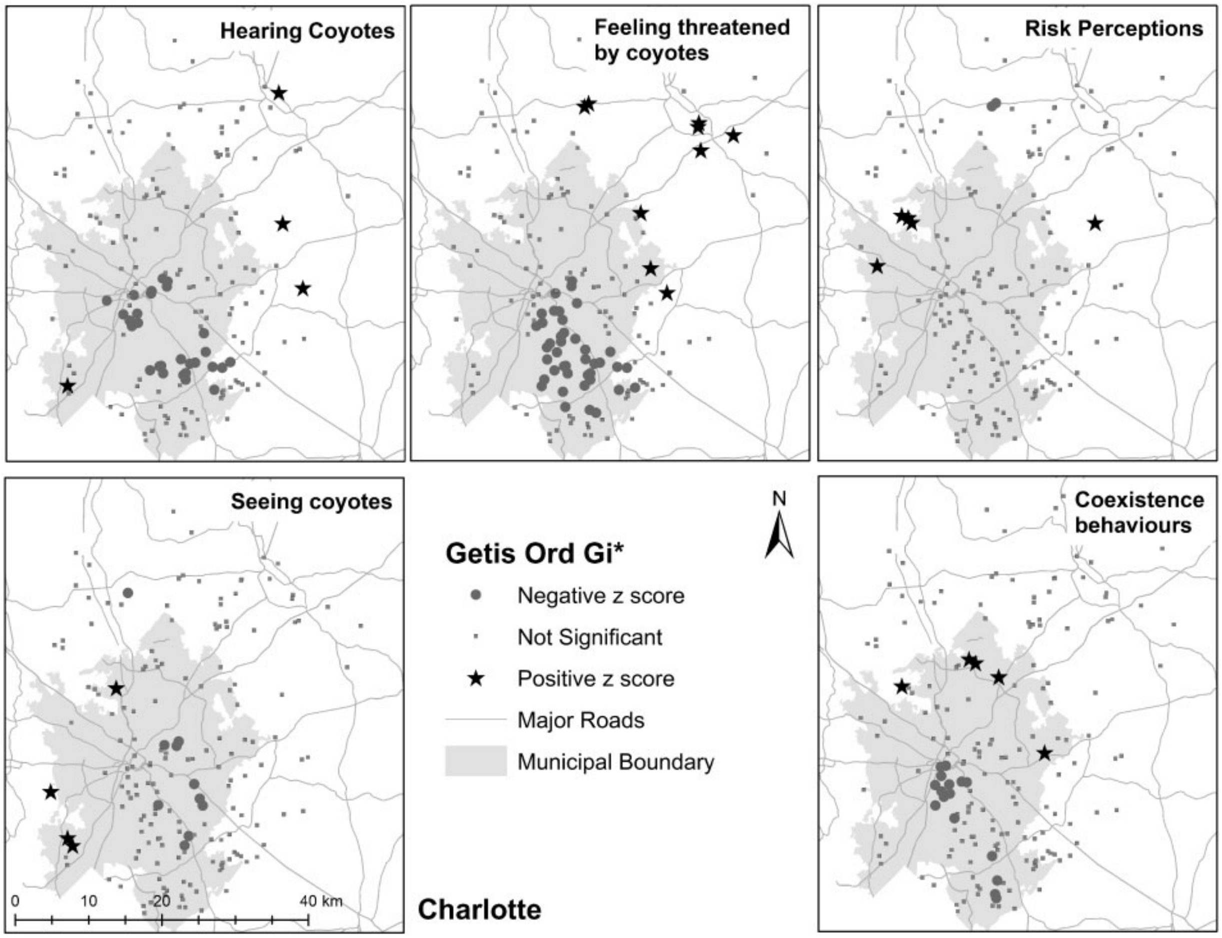

Figure 4: Charlotte hot spot analysis for coyote interactions, risk perception and coexistence behaviors. For statistically significant positive z-scores (denoted by stars), the larger the z-score is, the more intense the clustering of high values (i.e. hot spot). For statistically significant negative z-scores (denoted by larger circles), the smaller the z-score is, the more intense the clustering of low values (i.e. cold spot). Cold spots for all interaction types and coexistence behaviors occurred in the south central area of Charlotte. Risk perception showed hotspots on the northern peripheries of Charlotte.

research suggests interactions with coyotes can elevate risk perception and acceptance of their lethal control (Martínez-Espiñeira 2006; confirmed among this sample in Drake et al. 2019), this study suggests interactions may render lethal control less necessary by promoting coexistence behaviors as we measured them in this study. Contrary to studies finding that negative encounters decrease tolerance for carnivores (e.g. Kansky and Knight 2014; Kansky, Kidd, and Knight 2014), this study suggests that, instead of calling officials, respondents are empowered to respond to coyote presence with proactive, preventative measures, such as scaring off a coyote or feeding pets inside. Although most respondents in our sample did not encounter coyotes or have problems with coyotes, those who did considered non-lethal self-action to be effective. Herein, we present preliminary evidence for coexistence in that both attitude and behavior was consistent and common among our sample.

This study contributes to previous research by suggesting urban perceptions, tolerance and coexistence behaviors differ between the urban core and peripheral urban areas. The frequency of human–coyote interactions and where those interactions occur may be important variables to consider in predictive models of coexistence behavior (Wieczorek Hudenko, Siemer, and Decker 2008; Lute et al. 2016). Environmental variables comprising prime coyote habitat such as open space and forest cover may have influenced spatial patterns in the data. We know coyotes exist in the core urban areas (Gehrt, Anchor, and White 2009; unpublished data from the Human–Wildlife Interactions Database; anecdotal evidence exists in North Carolina specifically, R. Kays, pers. comm.), however, our analyses revealed cold spots in human–coyote encounters, suggesting coyotes may be more cryptic or rarer in urban cores. Environmental and species attributes such as short sight lines, adoption of nocturnal use patterns, spatial use patterns and smaller ranges, respectively, have been demonstrated to foster coexistence (defined as spatial but not necessarily temporal overlap; Riley et al. 2003; Carter et al. 2012, 2013). Thus, humans' contribution to coexistence may be easier in urban cores compared with areas where human–coyote encounters are higher. This finding lends support for co-adaptation between humans and coyotes that scholars have posited as a necessary condition for human–carnivore coexistence (Carter and Linnell 2016).

Social variables may also contribute to spatial patterns among cities and their socially stratified and ecologically distinct neighborhoods revealed in this study. In the sister publication to this study, city identity was noted to be a better predictor of coyote-related perceptions than most socio-demographic characteristics, except ethnicity (Drake et al. 2019). Similar to other socio-spatial studies, social identity may be driving spatial

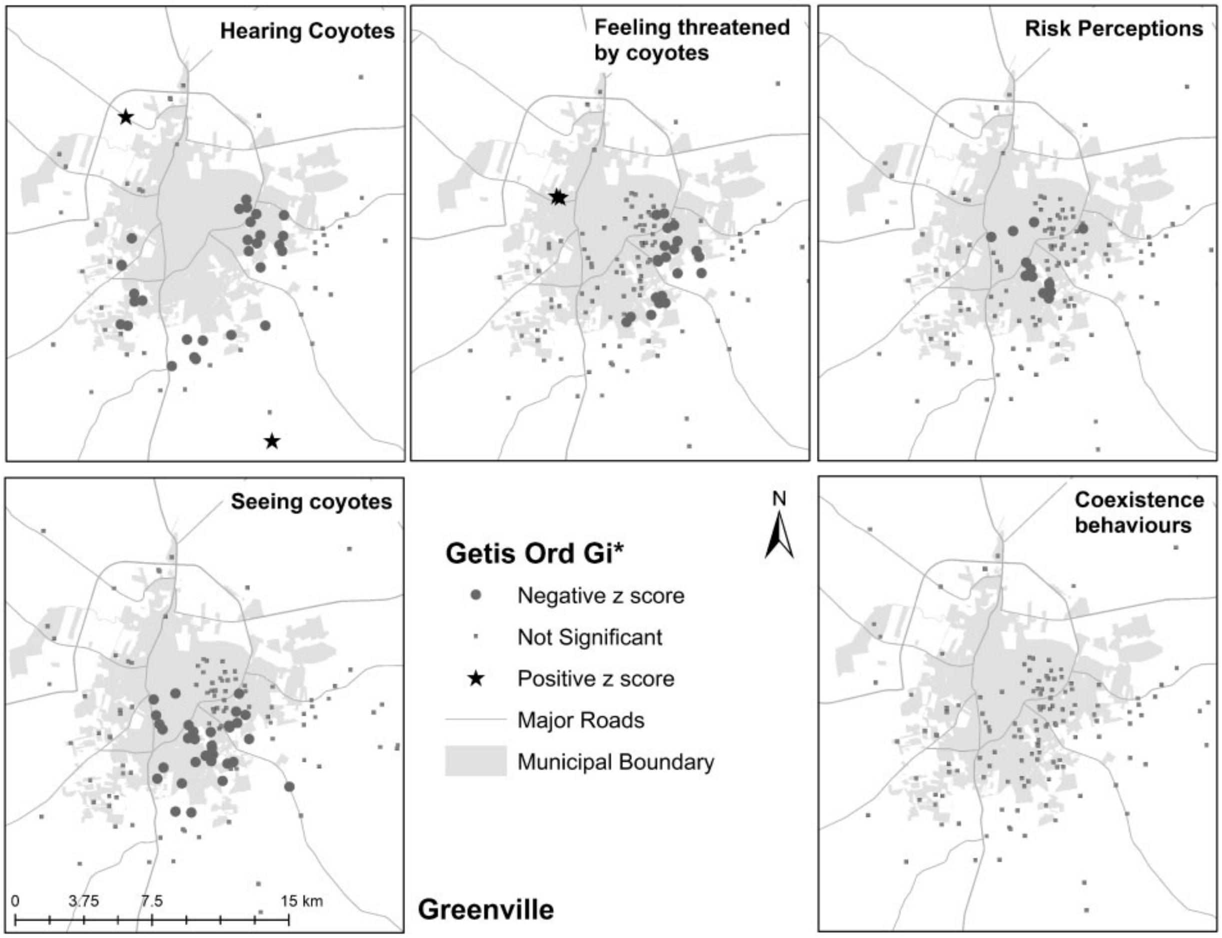

Figure 5: Greenville hot spot analysis for coyote interactions, risk perception and coexistence behaviors. For statistically significant positive z-scores (denoted by stars), the larger the z-score is, the more intense the clustering of high values (i.e. hot spot). For statistically significant negative z-scores (denoted by larger circles), the smaller the z-score is, the more intense the clustering of low values (i.e. cold spot). Center-east areas of Greenville showed cold spots for interactions with coyotes and risk perception.

patterns in attitudes toward an element in nature (Carter et al. 2014; Andrade et al. 2019). Respondents who felt threatened by coyotes were not located in hotspot areas of interactions with coyotes, which may reflect risk perceptions being lower for familiar risks than more novel ones (Slovic 1987). Thus, open space, deciduous forest, pastures, and the built environment may interact with social identities and indelible encounters between the two species to contribute to the spatial patterns of conflict and coexistence.

Additional research is needed to confirm this exploratory analysis and determine the socio-ecological predictors of conflict and causal relationships across urban contexts. Further exploration with larger datasets, in other socio-ecological systems, and analyzing ratios of various land cover classes may enhance understanding on this front. For example, mosaic landscapes with balanced open space and development may have different encounter rates and potential for conflict compared with a landscape of only low development and little open space. Additionally, not all open space is the same and finer details on land cover classes may reveal stronger relationships than we uncovered herein. Because stakeholders not typically targeted in carnivore governance, such as realtors or homeowners associations, may be best positioned to lead on neighborhood level coexistence, studies should also explore their perceptions, motivations, and preferences regarding carnivores. Finally, to paint the full coexistence picture, follow up studies to this study and other longitudinal research efforts are needed to understand how interactions change over time as well as space.

Given the challenges of wildlife conservation in the Anthropocene, the potentially important role of human–wildlife interactions in their full socio-ecological contexts should not be overlooked. Wildlife professionals could consider three management insights from this study. First, negative human–coyote interactions are associated with urban landscape types that attract both species (e.g. open areas, forests). Conflict may be avoided by designing interventions and risk communication to encourage appropriate risk-reducing responses in those specific socio-spatial contexts. Second, most citizens are willing to increase pet supervision and keep pets inside when needed to mitigate negative interactions with coyotes. Encouraging these coexistence behaviors among aware and latent aware stakeholders will go farther to reduce conflict than the false narratives promulgated by vocal stakeholders demanding management of coyotes rather than attractants. Further, this study suggests coyote management aimed at mitigating risks associated with pet attacks and rabies will more likely address primary concerns among stakeholders. Last, wildlife

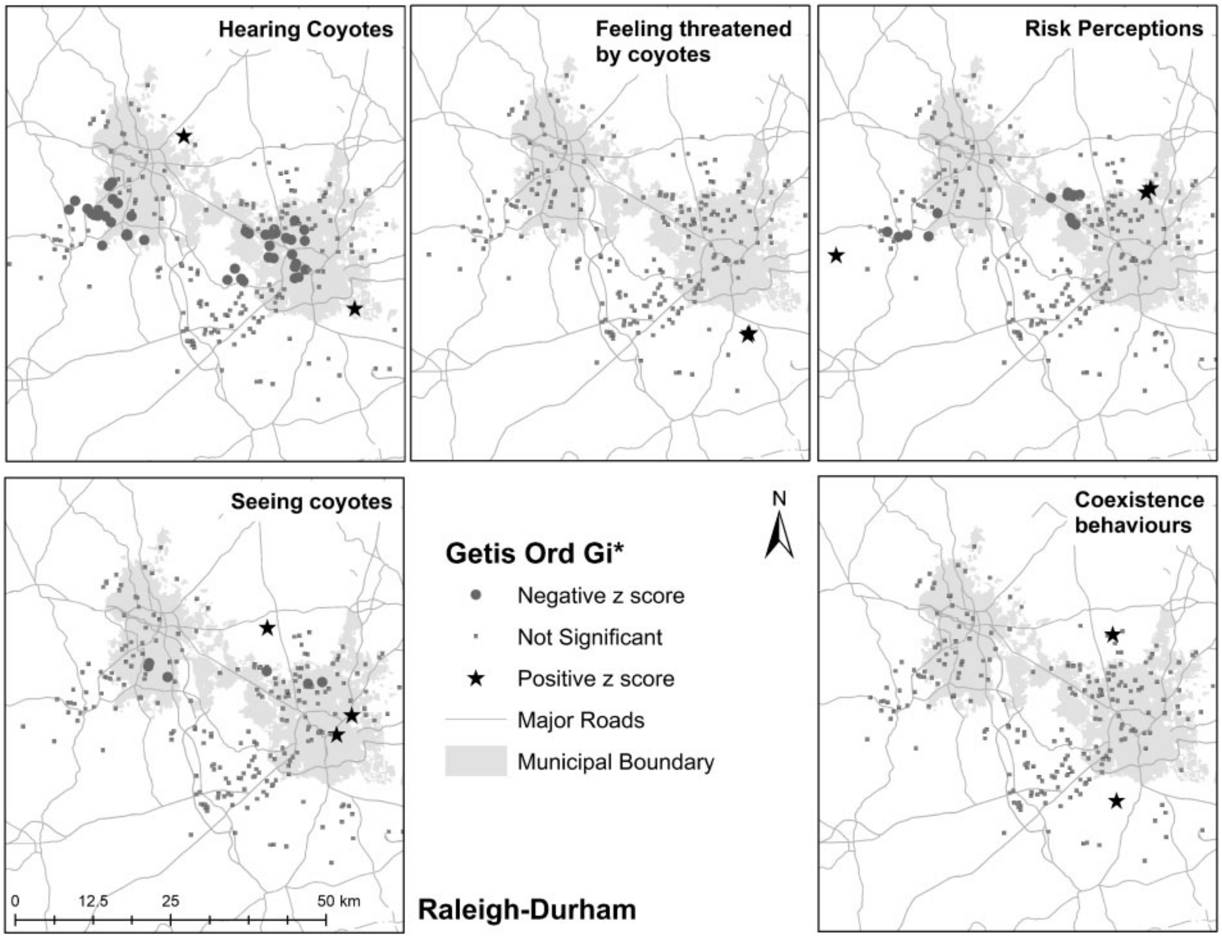

Figure 6: Raleigh–Durham hot spot analysis for coyote interactions, risk perception and coexistence behaviors. For statistically significant positive z-scores (denoted by stars), the larger the z-score is, the more intense the clustering of high values (i.e. hot spot). For statistically significant negative z-scores (denoted by larger circles), the smaller the z-score is, the more intense the clustering of low values (i.e. cold spot). Fewer discernable patterns exist for Raleigh–Durham, but hearing coyotes near the home and risk perception showed cold spots clustering.

professionals, researchers and stakeholders will need to continue exploring the socio-spatial dimensions of human–wildlife interactions to be nimble in the face of future environmental change. Human and wildlife ranges and land uses patterns will continue to shift with climate change and further development of the landscape, creating ever-dynamic relations between human and non-human species. An understanding of urban socio-ecological systems will be needed to prevent conflict and to effectively promote coexistence in this context.

Supplementary data

Supplementary data are available at *JUECOL* online.

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Data availability

The dataset resulting from this research is available as Supplementary Material and on the first author's ResearchGate profile: https://www.researchgate.net/profile/Michelle_Lute.

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