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RESEARCH ARTICLE

The influence of sociodemographic and environmental factors on wildlife carcass submissions in urban areas: Opportunities for increasing equitable and representative wildlife health surveillance

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Summary

Wildlife health surveillance is important in rapidly expanding urban areas, where wildlife live in close association with humans and face unique health risks. Urban areas are not homogeneous, and social and environmental factors may affect the distribution of surveillance data we receive from these environments. The Canadian Wildlife Health Cooperative (CWHC) operates a national wildlife surveillance programme that receives carcass submissions for diagnostic evaluation. Our objective was to evaluate sociodemographic and environmental factors associated with CWHC submissions within two cities in Ontario, Canada. Submissions were mapped at two geographic scales and linked with census and environmental data. The results of mixed multivariable Poisson and negative binomial regression analyses suggest that natural (e.g., percent parkland) and anthropogenic environmental (e.g., presence of a zoo) and social variables (e.g., low income) are associated with submissions at both administratively relevant scales. Associations that are common across scales may represent robust intervention points and inform surveillance methodology/messaging. Surveillance data may influence public health policy, wildlife management, and other decision-making regarding the benefits/risks associated with coexistence with wildlife. This study highlights gaps in surveillance methodology that may prevent equal opportunity for participation in wildlife health surveillance and enable equal opportunity to benefit from the associated outputs.

Key words: surveillance methodology, urban, wildlife, wildlife disease surveillance, wildlife health

Introduction

Healthy and sustainable wildlife populations are of significant environmental, economic, cultural, spiritual, and recreational importance. Wildlife health surveillance is an essential tool for understanding wildlife health, assessing public health risks (as they relate to wildlife and zoonotic disease), and

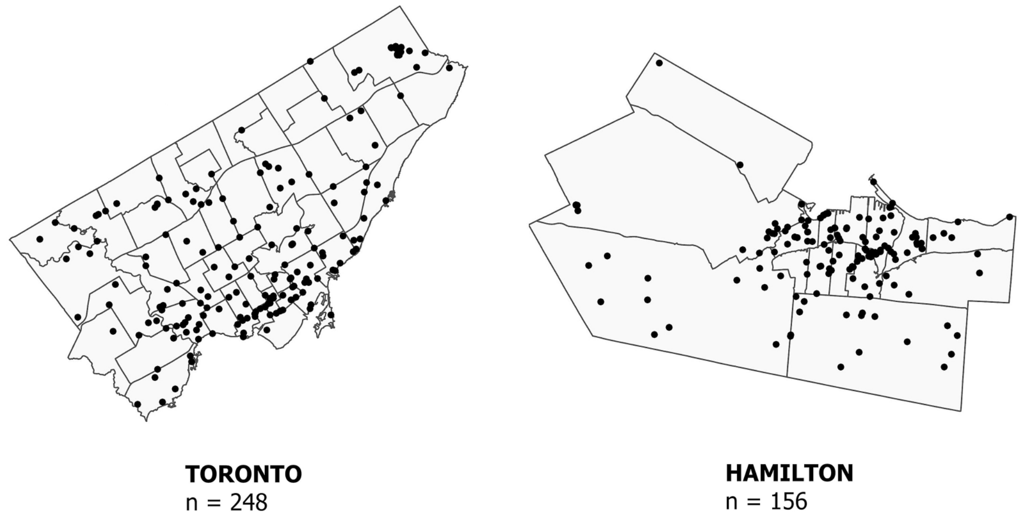

Fig. 1. Submitter provided collection location for wildlife samples submitted to the Canadian Wildlife Health Cooperative from Hamilton and Toronto, Ontario, Canada between January 2014 and December 2019. Ward boundaries for each city are shown. Boundary files were obtained from the City of Toronto (2021a) and City of Hamilton (2020) data portals. Projection: Canada Albers Equal Area Conic; Geographic coordinate system: GCS North American 1983.

informing policy decisions related to wildlife management and conservation (Belant and Deese 2010; Ryser-Degiorgis 2013). Surveillance is of particular importance in rapidly expanding urban areas, where wildlife live in close association with humans and face unique challenges and health risks compared to their non-urban counterparts (Murray et al. 2019). Even within urban areas, wildlife health and disease can vary across relatively small spatial scales according to host and environmental factors (e.g., variation in pathogen prevalence in Norway rats, *Rattus norvegicus*, between city blocks; Himsworth et al. 2013).

In Canada, the Canadian Wildlife Health Cooperative (CWHC) operates a national wildlife health surveillance programme that receives wild animal carcass submissions for diagnostic evaluation. The opportunistic reporting and submission of carcasses through the CWHC allows for data collection at spatial and temporal scales that would not otherwise be financially or logistically feasible. However, this method of data collection may be biased by environmental and sociodemographic factors that can impact whether surveillance outputs are representative of and relevant for the range of wildlife, human, and environmental elements in a given geographic area. Human sociodemographic variables are increasingly recognized for their relevance to wildlife health and citizen engagement. For example, previous research has demonstrated that socioeconomic heterogeneity can influence ecological processes, and both sociodemographic and environmental factors have been found to be associated with citizen engagement in reporting and surveillance related to wildlife (Pickett et al. 2017; Thomas-Bachli et al. 2020; Sánchez et al. 2021).

Owing to the nature of opportunistic surveillance, the majority of CWHC submissions come from ‘urban’ areas, resulting in ‘rural’ areas being commonly recognized as surveillance gaps. Urban areas, however, are not homogeneous (Cadenasso et al. 2007) and surveillance inputs may not be equally distributed across these heterogeneous environments. Urban areas can be evaluated at different scales, and different metrics may be used to define urban boundaries (e.g., city boundary, human population density, building density, land use; Moll et al. 2019); nevertheless, these metrics all tell us something

Table 1. Environmental and sociodemographic characteristics at the ward (based on Hamilton and Toronto data) and neighbourhood-level (based on Toronto data).

Explanatory variable	Category	No. of wards	No. of neighbourhoods
City	Hamilton	15	NA
	Toronto	47	140
Presence of a zoo	No	60	139
	Yes	2	1
Proportion high-rise dwellings[a]	$< 40\%$	33	80
	$\geq 40\%$	29	60
Proportion owned housing	$< 60\%$	38	91
	$\geq 60\%$	24	49
Proportion of census families with children	$< 60\%$	16	31
	$\geq 60\%$	46	109
Proportion of population with no knowledge of either official language[b]	$< 7\%$	45	117[e]
	$\geq 7\%$	17	23[e]
Proportion of population with graduate level training[c]	$< 30\%$	29	59
	$\geq 30\%$	33	81
Proportion of LIM-AT households[d]	$< 20\%$	32	80
	$\geq 20\%$	30	60
Percent area covered by parkland	$< 20\%$	50	101
	$\geq 20\%$	12	39
Population density	< 60 people per hectare	50	80
	≥ 60 people per hectare	12	60

[a]Defined by Statistics Canada as a building with 5 or more storeys.
[b]Official languages in Canada are English and French.
[c]Defined by Statistics Canada as including university certificate, diploma, or degree at a bachelor level or above.
[d]After-tax low-income measure (LIM-AT), defined by Statistics Canada as the percentage of economic families or unattached individuals who spend 20% or more of their income than average citizens on food, shelter, and clothing.
[e]Due to sample sizes, the categories for proportion of population with no knowledge of either official language were $< 5\%$ and $\geq 5\%$.

different about the environment and different scales may be relevant depending on the proposed purpose (e.g., management, policy, outreach) and the wildlife species being studied (e.g., home range, distribution). As there is no standardized definition of the word 'urban' and it can be interpreted in different ways (French, Giacinti, Robinson et al. 2022), in this article we instead refer to 'city' – an administratively relevant boundary that encompasses a complex mosaic of environmental and sociodemographic factors.

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Table 2. Univariable analyses of environmental and sociodemographic factors on submissions by ward in Hamilton and Toronto, Ontario, Canada based on mixed Poisson regression with a random intercept for ward.

Explanatory variable	Category	IRR	95% CI	*P*-value	Ward variance (95% CI)
City	Hamilton	Referent			
	Toronto	**0.25**	**0.14–0.42**	**< 0.001**	0.71 (0.43–1.17)
Presence of a zoo in ward	No	Referent			
	Yes	**10.21**	**2.67–39.05**	**0.001**	0.87 (0.52–1.43)
Proportion high-rise dwellings[a] in ward	< 40%	Referent			
	≥ 40%	**0.43**	**0.25–0.75**	**0.003**	0.96 (0.59–1.56)
Proportion owned housing in ward	< 60%	Referent			
	≥ 60%	1.40	0.77–2.53	0.268	1.09 (0.68–1.76)
Proportion of census families with children in ward	< 60%	Referent			
	≥ 60%	0.54	0.28–1.02	0.057	1.04 (0.64–1.68)
Proportion of population with no knowledge of either official language[b] in ward	< 5%	Referent			
	≥ 5%	**0.34**	**0.17–0.65**	**0.001**	0.96 (0.60–1.55)
Proportion of population with graduate level training[c]	< 30%	Referent			
	≥ 30%	0.85	0.47–1.53	0.592	1.12 (0.70–1.81)
Proportion of LIM-AT households[d] in ward	< 20%	Referent			
	≥ 20%	**0.39**	**0.23–0.69**	**0.001**	**0.95 (0.59–1.54)**
Percent area covered by parkland in ward	< 20%	Referent			
	≥ 20%	1.36	0.66–2.80	0.408	1.12 (0.69–1.79)
Density of ward	< 60 people per hectare	Referent			
	≥ 60 people per hectare	0.66	0.31–1.40	0.279	1.10 (0.68–1.77)

Note: Significant results are indicated in bold.
[a]Defined by Statistics Canada as a building with 5 or more storeys.
[b]Official languages in Canada are English and French.
[c]Defined by Statistics Canada as including university certificate, diploma or degree at a bachelor level or above.
[d]After-tax low-income measure (LIM-AT), defined by Statistics Canada as the percentage of economic families or unattached individuals who spend 20% or more of their income than average citizens on food, shelter, and clothing.

It is important to understand the current gaps in the representativeness of wildlife surveillance data within cities in order to inform methodology – the CWHC database provides us with an opportunity to generate this baseline understanding. Our objective was to evaluate the spatial distribution of wildlife carcass submissions to CWHC within Ontario cities and measure the associations between submissions and sociodemographic and environmental factors at different spatial scales.

Table 3. Mixed multivariable Poisson model with a random intercept for ward, exploring the association between environmental and sociodemographic factors and the number of submissions by ward in Hamilton and Toronto, Ontario, Canada.

Explanatory variable	Category	IRR	95% CI	*P*-value
City	Hamilton	Referent		
	Toronto	**0.19**	**0.12–0.31**	**< 0.001**
Presence of a zoo in ward	No	Referent		
	Yes	**5.73**	**2.39–13.74**	**< 0.001**
Proportion of LIM-AT households[a] in ward	< 20%	Referent		
	≥ 20%	**0.53**	**0.36–0.78**	**0.002**
Percent area covered by parkland in ward	< 20%	Referent		
	≥ 20%	**2.05**	**1.27–3.31**	**0.003**
Proportion owned housing in ward	< 60%	Referent		
	≥ 60%	**0.51**	**0.33–0.81**	**0.004**

Note: Significant results are indicated in bold. Random intercept for ward: variance = 0.30 (95% confidence interval [CI]: 0.15–0.58).

[a]After-tax low-income measure (LIM-AT), defined by Statistics Canada as the percentage of economic families or unattached individuals who spend 20% or more of their income than average citizens on food, shelter, and clothing.

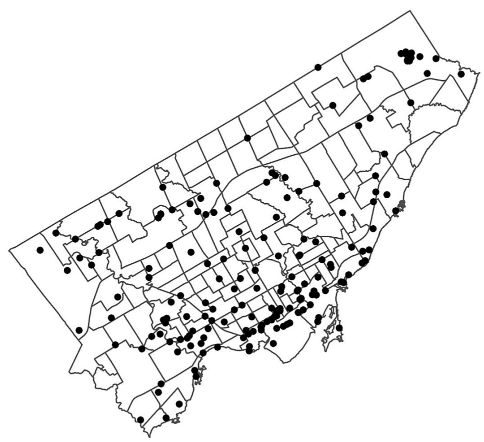

Fig. 2. Submitter provided collection location for wildlife samples submitted to the Canadian Wildlife Health Cooperative from Toronto, Ontario, Canada between January 2014 and December 2019. Neighbourhood boundaries for each city are shown. Boundary files were obtained from the City of Toronto (2021b) data portal. Projection: Canada Albers Equal Area Conic; Geographic coordinate system: GCS North American 1983.

Materials and Methods

Records were retrieved for all wild animal carcasses submitted to the Ontario-Nunavut node of the CWHC between January 2015 and December 2019. Submissions with missing dates, location, or species information were excluded. The CWHC does not regularly receive fish specimens in this region; therefore, the small number of fish records were excluded from analysis.

Table 4. Univariable analyses of environmental and sociodemographic factors on submissions by neighbourhood in Toronto, Ontario, Canada based on mixed negative binomial regression with a random intercept for neighbourhood.

Explanatory variable	Category	IRR	95% CI	*P*-value	Neighbourhood variance (95% CI)
Presence of a zoo in neighbourhood	No	Referent			1.03 (0.64–1.67)
	Yes	**18.91**	**2.47–144.47**	**0.005**	
Proportion high-rise dwellings[a] in neighbourhood	< 40%	Referent			1.07 (0.67–1.71)
	≥ 40%	**0.48**	**0.29–0.80**	**0.005**	
Proportion owned housing in neighbourhood	< 60%	Referent			
	≥ 60%	1.07	0.63–1.82	0.805	1.21 (0.77–1.90)
Proportion of census families with children in neighbourhood	< 60%	Referent			
	≥ 60%	0.66	0.37–1.18	0.160	1.17 (0.74–1.85)
Proportion of population with no knowledge of either	< 7%	Referent			
official language[b] in neighbourhood	≥ 7%	**0.46**	**0.22–0.99**	**0.047**	1.19 (0.76–1.87)
Proportion of population with graduate level[c] training in	< 30%	Referent			
neighbourhood	≥ 30%	1.32	0.79–2.22	0.285	1.19 (0.75–1.87)
Proportion of LIM-AT households[d] in neighbourhood	< 20%	Referent			
	≥ 20%	**0.29**	**0.17–0.47**	**< 0.001**	**0.88 (0.54–1.43)**
Percent area covered by parkland in neighbourhood	< 20%	Referent			
	≥ 20%	1.54	0.90–2.64	0.115	1.14 (0.71–1.81)
Density of neighbourhood	< 60 people per hectare	Referent			
	≥ 60 people per hectare	0.66	0.39–1.10	0.110	1.17 (0.74–1.86)

Note: Significant results are indicated in bold.
[a]Defined by Statistics Canada as a building with 5 or more storeys.
[b]Official languages in Canada are English and French.
[c]Defined by Statistics Canada as including university certificate, diploma, or degree at a bachelor level or above.
[d]After-tax low-income measure (LIM-AT), defined by Statistics Canada as the percentage of economic families or unattached individuals who spend 20% or more of their income than average citizens on food, shelter, and clothing.

We analysed these data using more than one administrative boundary, to identify factors that are common across scales, generate robust results, and increase the likelihood that the associations may be generalizable to other cities. Furthermore, sociodemographic information is not always available at comparable scales in all cities. Therefore, carcass submissions within city boundaries were mapped to visualize the distribution at two spatial scales that are of relevance for city planning and decision-making: ward and neighbourhood. An analysis at the ward level was conducted because it is a boundary for which census data are available and it is a standard administrative boundary that exists across cities allowing a multiple city analysis. Ward boundaries change over time based on population and other demographic changes. Neighbourhoods are an administratively defined boundary that provide social and demographic data at a smaller and more meaningful scale to assist local government and other community organizations with planning. Neighbourhood boundaries change very infrequently over time allowing for longitudinal comparison but are defined differently across municipalities; therefore, multiple city analysis may not be possible.

Table 5. Mixed multivariable negative binomial model with a random intercept for neighbourhood, exploring the association between environmental and sociodemographic factors and the number of submissions by neighbourhood in Toronto, Ontario, Canada.

Explanatory variable	Category	IRR	95% CI	*P*-value
Presence of a zoo in neighbourhood	No	Referent		
	Yes	**7.17**	**1.33–38.54**	**0.022**
Proportion of LIM-AT households[a] in neighbourhood	< 20%	Referent		
	≥ 20%	**0.28**	**0.18–0.46**	**< 0.001**
Percent area covered by parkland in neighbourhood	< 20%	Referent		
	≥ 20%	**1.73**	**1.07–2.79**	**0.026**

Note: Significant results are indicated in bold Random intercept for neighbourhood: variance = 0.66 (95% confidence interval [CI]: 0.38–1.14).

[a]After-tax low-income measure (LIM-AT), defined by Statistics Canada as the percentage of economic families or unattached individuals who spend 20% or more of their income than average citizens on food, shelter, and clothing.

Ward level

Cities for which there were more than 150 wild animal carcass submissions across the 5-year study period were selected to ensure a robust sample size for regression analysis. Carcass location coordinates that were included for ward-level analysis were classified by ward using geospatial data obtained through municipal open access data portals (City of Hamilton 2020; City of Toronto 2021a).

Neighbourhood level

Carcass location coordinates were classified by neighbourhood using geospatial data obtained through municipal open access data portals (City of Toronto 2021b).

Census data at the ward and neighbourhood level

The following social and demographic variables were extracted from ward and neighbourhood profiles (produced using data from the 2016 census) from the City of Hamilton and the City of Toronto websites: population density (people per hectare), housing variables (proportion of high-rise dwellings, proportion of owned houses), family structure (proportion of census families with children), language (proportion of population with no knowledge of either official language), education (proportion of population with university certificate, diploma, or degree at a bachelor level or above), and income (proportion of low-income households based on the Statistics Canada after-tax low-income measure, LIM-AT; City of Hamilton 2018a, 2018b, 2018c, 2018d, 2018e, 2018f, 2018h; City of Toronto 2018; City of Toronto 2019a). The following environmental variables were determined at the ward and neighbourhood level: presence of a zoo (yes or no) and percent area covered by parkland. Percent area covered by parkland was calculated in ArcGIS 10.7 using open access environmental data (City of Hamilton 2018g; City of Hamilton 2020; City of Toronto 2019b; city of Toronto 2021a, and 2021b). City was recorded as an additional variable where relevant (i.e., submissions from multiple cities).

Regression analysis at the ward and neighbourhood level

Linearity was assessed using locally weighted regression scatterplot smoothing (lowess) curves between the log of the number of submissions per ward/neighbourhood and continuous independent variables. Variables found to have a non-linear relationship with the outcome were categorized if the relationship could not be modelled by adding a quadratic term. Categorizations were made in consideration of the range of values for each independent variable while accounting for sample size (i.e., ensuring a sufficient sample size in each category).

To avoid issues with collinearity, Pearson correlation coefficients were used to estimate the correlation between all variables. Variables were considered highly correlated if they had a coefficient greater than |0.8|. In the case of high correlation, the variable with the lower p-value on univariable analysis was selected for inclusion in the multivariable model.

For each dataset (i.e., at the ward level and at the neighbourhood level), univariable mixed Poisson regression models were fitted to identify associations between the rate of submissions per ward/neighbourhood and the social, demographic, and environmental variables described above. The number of submissions was included as the dependent variable, and the natural log of the human population of the neighbourhood or ward was included as an offset in all models. Multivariable mixed Poisson models were fitted using backwards stepwise elimination including all variables in the model. Variables were retained in the model if they were statistically significant or acted as explanatory antecedents or distorter variables (i.e., confounding variables). Variables were considered to have a confounding effect if they were not intervening variables and their removal resulted in a change in the direction or significance of a statistically significant model coefficient. Pairwise interactions were not explored due to limited sample size. In ward-level models, a random intercept was included for ward, and in neighbourhood-level models, a random intercept was included for neighbourhood to account for autocorrelation within a small geographic area.

Model fit was first evaluated by fitting a mixed negative binomial regression and evaluating the overdispersion parameter, alpha. If alpha was significant, the multivariable model was fit as a negative binomial model moving forward (note: in this instance, the univariable models were also re-run using univariable mixed negative binomial regression models). Following this, model fit was assessed using a normal quantile plot of the Anscombe residuals to assess normality. In addition, best linear unbiased predictions (BLUPs) were evaluated by graphic visualization of the normality and homoscedasticity of the BLUPs. If the BLUPs did not meet these assumptions, Akaike information criteria were assessed to determine whether model fit was improved by the inclusion of the random intercept. Pearson residuals were plotted to identify potential outliers.

All mapping was done using ArcGIS 10.7 (ESRI, Redlands, California, USA). STATA version 15.0 (STATACorp, College Station, Texas 2018) and a significance level of $\alpha = 0.05$ were used for all analyses.

Results

Ward level

Hamilton and Toronto were the only two cities in Ontario with more than 150 carcass submissions over the 5-year study period. The ward models in use during the 2016 Canadian Census were used because they were the boundaries in place during the study period. During this period, Toronto and Hamilton had 47 and 15 wards, respectively.

There were a total of 404 submissions, 248 from Toronto and 156 from Hamilton. The number of submissions in each ward ranged from 0 to 41, with a mean of 6.5 and median of 4. There were 6 wards (9.7%) with no submissions (**Fig. 1**).

All continuous independent variables were categorized as low/high (**Table 1**). After categorization, there were no strong correlations between any of the independent variables.

Based on univariable mixed Poisson models, the number of submissions was positively associated with the following independent variables: presence of a zoo (Table 2).

Based on univariable mixed Poisson models, the number of submissions was negatively associated with the following independent variables: city, proportion of high-rise dwellings, proportion of population with no knowledge of either official language, and proportion of low-income households (Table 2).

The final mixed multivariable Poisson model included: city, proportion of owned houses, proportion of low-income households, presence of a zoo, and percent area covered by parkland. The rate of submissions by ward was significantly higher where a zoo was present and there was a high percent of parkland. There was a statistically significant negative association between ward submissions and higher proportion of owned houses, and higher proportion of population in low income. The rate of submissions was significantly lower in Toronto than Hamilton (Table 3).

The Anscombe residuals were normal. Ward was a significant random intercept for which the variance is presented in Table 3. Overall model fit was improved by the inclusion of ward as a random intercept.

Neighbourhood level

Submissions from Toronto were used for the neighbourhood-level analysis. Toronto had a 140 neighbourhood model in use during the study period. There were a total of 248 submissions. The number of submissions in each neighbourhood ranged from 0 to 40, with a mean of 1.8 and a median of 1. There were 59 neighbourhoods (42.1%) with no submissions (Fig. 2).

All independent variables were categorized as either low/high. After categorization, there were no strong correlations between any of the independent variables.

Based on univariable mixed negative binomial models, the number of submissions was positively associated with the following independent variables: presence of a zoo (Table 4).

Based on univariable mixed negative binomial models, the number of submissions was negatively associated with the following independent variables: proportion of high-rise dwellings, proportion of population with no knowledge of either official language, and proportion of low-income households (Table 4).

The final mixed multivariable negative binomial model included: proportion of low-income households, presence of a zoo, and percent area covered by parkland. The rate of submissions by a neighbourhood was significantly higher where a zoo was present and there was a high percent of parkland. The rate of submissions was significantly lower in neighbourhoods with a higher proportion of low-income households (Table 5).

The Anscombe residuals were normal. Neighbourhood was a significant random intercept for which the variance is presented in Table 5. Overall model fit was improved by the inclusion of neighbourhood as a random intercept.

Discussion

Our study presents an evaluation of the factors associated with carcass submissions to the CWHC within two major cities in Ontario, Canada at two different administratively relevant scales, which highlights some of the aspects that may limit public engagement in wildlife health surveillance. The following discussion focuses on those variables that were significantly associated with the rate of submissions at both administrative scales. Our findings suggest that natural and anthropogenic environmental (e.g., parkland and presence of a zoo) and social (e.g., low-income status) variables are associated with submissions at both the ward and neighbourhood levels. City-wide aggregate data are quite broad and may not capture important associations that emerge at finer scales; therefore, it was important to evaluate the data across smaller administrative boundaries within cities. Geographic areas within cities, however, are aggregated at multiple different spatial scales for planning, management, and electoral purposes, and cities may use different methods to divide their administrative boundaries spatially. Surveillance data should ideally be available and assessed at a spatial scale of relevance for wildlife health, city planning, and decision-making.

Geographic features of the environment influence the likelihood of detecting carcasses, human behaviour in these spaces, and suitability for wildlife populations. In our study, there were more samples submitted from areas with a higher proportion of parkland. Parkland may be more likely to have more open space (i.e., fewer visual obstacles), which may aid in the visual detection of carcasses. Additionally, how humans use these spaces, including activities like dog walking, may result in the discovery of animal carcasses in parkland. While parkland habitat may be more suitable and desirable for some species (Ordeñana et al. 2010), we know that some wild species are present in high densities in non-parkland (e.g., raccoons, *Procyon lotor*; Gross et al. 2012). Due to limitations related to sample size and the availability of wildlife distribution data, we were unable to control for species and density. It would also be useful to further refine the parkland variable to account for the quality and accessibility of parkland, from both human recreational and wildlife habitat perspectives.

When considering parkland, it is also important to be aware of observed inequalities in the distribution of parkland. Previous research has identified that greenspace is unequally distributed across urban landscapes (Statistics Canada 2021; Tooke et al. 2010). In particular, associations have been found between socioeconomic factors, including household income, and proximity and access to green spaces. A study conducted in three major cities in Canada (Montreal, Toronto, and Vancouver) reported that high income had the most consistent and strong positive correlation with vegetation (Tooke et al. 2010). Urban greenspace development is associated with a complex social and historical context; an examination of these factors, while important, was outside the scope of this paper. It is of note, however, that even after controlling for parkland, there was a negative association between the rate of carcass submissions and the proportion of low-income households. There are a number of potential factors that may underlie this association, including the distribution of services and funding related to wildlife in these areas, and/or how people view and value wildlife. Manfredo et al. (2020) found that socioeconomic factors (e.g., higher education and income) were associated with a shift in values from being human-centric towards equality between humans and wildlife. However, this is likely a very complex relationship and it is important to acknowledge this was an ecological study and, therefore, we must be cautious not to infer associations at the individual level based on group-level data (i.e., ecological fallacy).

A range of complex social factors may influence wildlife health surveillance programmes that rely on public participation; however, many are not easily measured by census data including: awareness of the service and wildlife health issues, a knowledge of the importance/relevance of the service, and motivations and barriers to participation. There is currently a limited focus on how these social factors influence wildlife surveillance programmes and how they may lead to bias in surveillance inputs and outputs. Future research that surveys people who have and have not participated in wildlife health surveillance can begin to build this knowledge base and may help to inform future surveillance methodology and messaging.

Wildlife surveillance programmes have made efforts to increase participation of certain public groups (e.g., engagement of hunters and trappers) and help address previously identified gaps in data (e.g., targeting remote vs. populated areas, and particular wildlife species). Similar methods may be useful to address the gaps in intra-city data; however, identifying opportunities for increasing equitable and representative wildlife health surveillance requires a thorough understanding of the influence of environmental and sociodemographic factors on surveillance inputs and outputs. Some examples of methods used by the CWHC include education, messaging, and the development of online tools to facilitate the submission process (i.e., online reporting tool; http://www.cwhc-rcsf.ca/report_and_submit.php). Additionally, targeted relationship building has been a successful approach. For example, collaboration with pest control companies to collect species that are generally underrepresented but of public health importance (e.g., Norway rats; Robinson et al. 2022). Our analysis highlights that this approach is also useful within cities. Based on our knowledge of longstanding relationships between zoo facilities and the CWHC, presence of a zoo in the ward/neighbourhood was included as a fixed effect in our models, and unsurprisingly those wards/neighbourhoods had a higher rate of submissions.

Our study highlights the importance of considering both social and environmental factors when evaluating whether wildlife surveillance data are representative of a given geographic area. The submission of wildlife carcasses in cities likely depends on a number of factors including: the distribution of services and funding related to wildlife, presence of carcasses, detection of carcasses, a willingness or ability to make submissions, but also a knowledge of the service and a knowledge of the importance/relevance of the service. In addition, human population size and geographic proximity to a submission centre may influence carcass submissions (e.g., Hamilton and Toronto are among the most populous cities in Ontario and geographically close to the Ontario node of the CWHC in Guelph, Ontario). An understanding of these relationships can build awareness of potential biases not only in the design and implementation of surveillance programmes but also in the data, analysis, interpretation, and communication of resulting information. Understanding these complex relationships is increasingly pertinent as urbanization continues to increase globally; thus, further research is required to better understand the patterns and processes affecting urban wildlife health throughout the world. As surveillance data may influence public health policy, wildlife management, and other wildlife-related decision-making, it is imperative we increase our ability to identify barriers that may prevent equal opportunity to participate in wildlife health surveillance and to benefit from the associated outputs.

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Author contributions

JAG, SJR, SKF, DLP, and CMJ conceived and designed the study. JAG, SJR, and SKF performed the experiments/collected the data. JAG, SJR, and SKF analyzed and interpreted the data. DLP and CMJ contributed resources. JAG, SJR, SKF, DLP, and CMJ drafted or revised the manuscript.

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Competing interests

The authors declare there are no competing interests.

Data availability

Data are available from the authors upon reasonable request and with permission of the Canadian Wildlife Health Cooperative.

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