



Land Use and Dog Park Associations with *Escherichia coli* in the Chattahoochee River National Recreation Area Watershed



Bag and Bin-it station at the Chattahoochee River National Recreation Area
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Land use and dog park associations with *Escherichia coli* in the Chattahoochee River National Recreation Area watershed

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Contents

	Page
Figures.....	iv
Tables	iv
Abstract.....	v
Acknowledgments.....	vi
Abbreviations.....	vii
Introduction.....	1
Methods.....	2
Data acquisition.....	2
Statistical analysis	5
Results.....	7
Discussion.....	15
Literature Cited	18
Appendix A	21
Appendix B	28

Figures

	Page
Figure 1. Digital elevation (in meters) map of Chattahoochee River National Recreation Area watershed (CHAT) with sample locations (Chattahoochee Riverkeeper Neighborhood Water Watch (CRK NWW sample sites) and dog parks.	3
Figure 2. Sample size and median <i>Escherichia coli</i> concentrations across study sites.....	8
Figure 3. Seasonal <i>Escherichia coli</i> (<i>E. coli</i>) most probable number (MPN) per 100 milliliter concentration (a) and seasonal <i>E. coli</i> beach action value (BAV) exceedance rate (b).	9

Tables

	Page
Table 1. Response and explanatory variables used for forward stepwise linear regression and Spearman rank correlations.	4
Table 2. Forward stepwise linear regression results for seasonal <i>Escherichia coli</i> (<i>E. coli</i>) concentration (log-transformed seasonal median values). Italicized font indicates statistically significant model terms with $p < 0.05$	11
Table 3. Forward stepwise linear regression results for seasonal <i>E. coli</i> beach action value (U.S. Environmental Protection Agency 2012) exceedance rate (percent of samples with <i>E. coli</i> concentrations > 235 most probable number per 100 milliliters).	12
Table 4. Spearman rank correlations (ρ) between <i>Escherichia coli</i> concentration (log-transformed seasonal median values) and dog park metrics.	13
Table 5. Spearman rank correlations (ρ) between <i>Escherichia coli</i> beach action value exceedance rate (percentage of samples exceeding the U.S. Environmental Protection Agency beach action value of 235 most probable number per 100 milliliters) and dog park metrics.	14
Table 6. List of dog parks in the Atlanta, Georgia Metropolitan Area.	21
Table 7. Study site GPS coordinates and site characteristics.	28

Abstract

A recent study in the Chattahoochee River National Recreation Area (CHAT) indicated that dogs were a primary source of fecal contamination in the Chattahoochee River and that at least some of the contamination in the river was coming from locations outside of CHAT. The study herein sought to determine if dog parks in the CHAT watershed were sources of dog fecal contamination in streams within the watershed. *Escherichia coli* (*E. coli*) data were compiled from the Chattahoochee Riverkeeper Neighborhood Water Watch (NWW) program for sites within the CHAT watershed. Information about dog park locations within the Atlanta metropolitan area was compiled through online searches. Wilcoxon rank-sum tests, forward stepwise linear regression, and Spearman rank correlations were used to investigate the relations between seasonal *E. coli* levels (*E. coli* concentration and the proportion of samples that exceeded the U.S. Environmental Protection Agency beach action value [BAV]) and dog parks within the drainage basins. NWW sites with dog parks within the drainage basins had higher *E. coli* concentrations in the summer and winter, and samples exceeded the BAV more frequently in the winter than sites without dog parks within the drainage basins. *Escherichia coli* levels in the summer and winter were positively correlated with the number of dog parks within the drainage basins, indicating that *E. coli* concentrations and the frequency of BAV exceedances were seasonally higher at sites with more dog parks than at sites with fewer dog parks within the drainage basins. *Escherichia coli* concentrations in the summer were negatively correlated with distance to the nearest dog park in the drainage basin, indicating that sites with at least one dog park in close proximity had higher *E. coli* concentrations in the summer than sites for which the closest dog park was more distantly located. However, results of this study may have been influenced by the high degree of spatial autocorrelation in the data caused by overlapping drainage basins. Additionally, *E. coli* occurs in the gut systems of many species, so concentrations of *E. coli* may not represent levels of dog fecal contamination. Dog waste in residential yards and neighborhoods is a possible source of contamination in the watershed that could be investigated in future studies on sources of fecal contamination in the CHAT watershed. Utilizing dog-specific genetic markers in future studies would help reduce ambiguity in data interpretation.

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Improperly disposed dog waste is a potential source of *Escherichia coli* in waterways in the Chattahoochee River National Recreation Area. © SALLY BETHEA

Abbreviations

BAV: Beach action value

BIC: Bayesian information criterion

CHAT: Chattahoochee River National Recreation Area

CNPC: Chattahoochee National Park Conservancy

CRK: Chattahoochee Riverkeeper

Devel: Percent of drainage area with developed land use

Forest: Percent of drainage area with forested land use

GPS: Global positioning system

Imp: Percent of drainage area with impervious surface area

km: Kilometer

mL: Milliliter

MPN: Most probable number

NWW: Neighborhood Water Watch

Precip: Median seasonal 24-hour antecedent cumulative precipitation

VIF: Variance inflation factor

Introduction

The Chattahoochee River National Recreation Area (CHAT) is a popular recreation destination in the Atlanta, Georgia metropolitan area. In 2020, CHAT received 3.1 million visitors; this was an increase of 7% in visitation from 2018 (<https://irma.nps.gov/STATS/>, accessed November 30, 2021) despite the closure of CHAT for several months in response to the coronavirus pandemic. Many Park visitors bring dogs. Previous studies have found that dog waste in public areas can be a source of pathogenic bacteria (Ahmed et al. 2015) and antibiotic resistant *Escherichia coli* (Procter et al. 2014, Ahmed et al. 2015, Ortega-Paredes et al. 2019, Worsley-Tonks et al. 2021). Approximately 30% of CHAT visitors participate in water-based recreation such as fishing, swimming, tubing, and kayaking. Because of the high number of people recreating in the water, presence of contaminants that pose a risk to human health is a primary concern to CHAT management. A recent study in CHAT watersheds used genetic markers to detect bacteria that inhabit the intestinal tract of specific host taxa and identify sources of fecal contamination (McKee et al. 2020). Results from the McKee et al. (2020) study indicated that dogs were frequent contributors of fecal contamination in the Chattahoochee River. McKee et al. (2020) also found that levels of the dog fecal genetic marker in the Chattahoochee River were significantly correlated with *E. coli* concentrations, which are used as a surrogate for human health risks from exposure to fecal contamination. Further, among the potential sources that were screened, the dog fecal marker was the best predictor of presence of the enterococcal surface protein, a marker indicative of the presence of pathogenic enterococcus (Scott et al. 2005). As a result of the McKee et al. (2020) study, the Chattahoochee National Park Conservancy (CNPC) and the National Park Service (NPS) have installed new dog waste stations throughout the Park. However, the detection of dog contamination at high levels (greater than or equal to 10 copies per 1 mL) in samples from 10 of the 11 study sites outside CHAT boundaries but within the CHAT watershed in the McKee et al. (2020) study indicates that dog fecal contamination is also entering CHAT from origins outside the Park.

Effective plans to mitigate dog fecal contamination within CHAT require a better understanding of the origins of fecal contamination. Logically, dog parks are probable sources of contamination when rainfall runoff transports contaminants from the landscape to waterways. This study investigated the associations between levels of *E. coli* from citizen-science collected stream samples across the CHAT watershed and the surrounding land use to assess if dog parks in the CHAT watershed are associated with *E. coli* levels. Dog park metrics used in the analysis included proximity between the sample site and the nearest dog park upstream in the drainage basin, number of dog parks within the drainage basin, and density of dog parks within the drainage basin. If dog parks in the CHAT watershed are associated with *E. coli* levels, the hypothesis would be supported that dog parks could be sources of fecal contamination in the CHAT watershed and could indicate that dog parks could be locations for targeted outreach efforts to reduce improperly disposed dog waste.

Methods

Data acquisition

A list of dog parks was compiled from internet searches for dog parks in the Atlanta metropolitan area and searches for Atlanta metropolitan area city and county parks websites for cities and counties within the CHAT watershed boundary (below Buford Dam). This search included 5 counties and 26 cities. For county and city websites that did not include information about dog parks, the associated county or city recreation department was contacted for further information. Fifty-four dog parks in the Atlanta metropolitan area were documented from this process (Appendix A). Global positioning system (GPS) coordinates for the dog parks were mapped in ArcMap (v.10.5.1, Environmental Systems Research Institute, Redlands, CA)¹. Twenty-seven dog parks from the compiled list were determined to be located within the CHAT watershed below Buford Dam (Figure 1; Appendix A) based on the aerial extent of CHAT and utilizing the “select by location” tool in ArcMap.

¹ Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

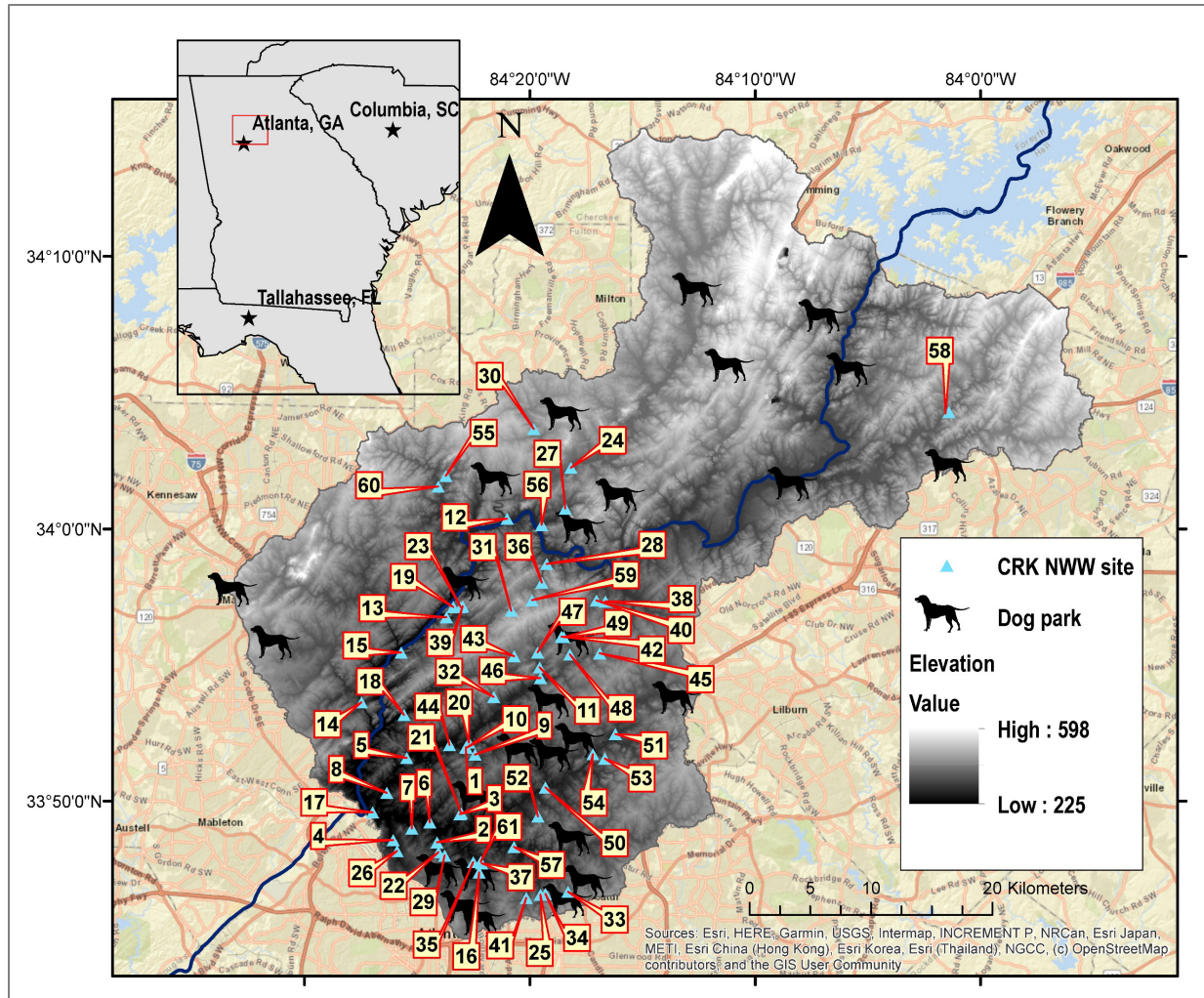


Figure 1. Digital elevation (in meters) map of Chattahoochee River National Recreation Area watershed (CHAT) with sample locations (Chattahoochee Riverkeeper Neighborhood Water Watch (CRK NWW sample sites) and dog parks. Site information associated with the site numbers is available in Appendix B.

Escherichia coli data from the Chattahoochee Riverkeeper Neighborhood Water Watch (CRK NWW) were obtained from the online database (<https://nww.chattahoochee.org/DataPage>, accessed October 14, 2021) for all CRK NWW sites within the CHAT watershed below Buford Dam. The CRK NWW is a citizen-science supported water monitoring program that began in 2010. Grab samples are collected from waterbodies in the Chattahoochee River watershed by CRK NWW volunteers from local communities and are then analyzed for *E. coli* with the IDEXX Colilert-18 system (Idexx Laboratories, Inc., Westbrook, ME) by the Chattahoochee Riverkeeper (for a list of CRK laboratory locations, see <https://chattahoochee.org/wp-content/uploads/2018/08/NWW-Handout-8-22-17.pdf>, accessed May 17, 2022). Sample collection dates for *E. coli* records available for analysis in this study ranged from August 2018 to October 2021. One record out of 3,848 records for sites within the CHAT watershed was noted as a duplicate and removed from analysis.

Precipitation can influence levels of dog waste in streams and rivers by carrying waste via overland runoff. Failure to account for the potential effect of precipitation on *E. coli* levels could mask possible relationships between *E. coli* and the explanatory variables of interest. To account for the possible influence of precipitation on *E. coli* levels, we obtained precipitation data associated with the *E. coli* data from the CRK NWW (<https://nww.chattahoochee.org/DataPage>, accessed October 14, 2021) for inclusion as an explanatory variable in the forward stepwise linear regression (Table 1). The precipitation data available on the CRK NWW website are the antecedent 24-hour cumulative precipitation from the most proximal rainfall gage in the Weather Underground network (<https://www.wunderground.com/history>) for the zip code of the CRK laboratory where that sample was processed. Therefore, the precipitation data available through the CRK NWW provide a rough estimate for the sample site and do not account for localized weather conditions for the sample site. Because of the differences in samples sizes across seasons (and differences in the associated number of precipitation values) among sites, median seasonal precipitation (precip) values were used for analysis.

Table 1. Response and explanatory variables used for forward stepwise linear regression and Spearman rank correlations.

Variable name	Description	Transformation	Variable type	Data source ^A
<i>E. coli</i> concentration	Seasonal median <i>E. coli</i> concentration	log	Response	CRK NWW
BAV exceedance rate	Seasonal proportion of <i>E. coli</i> concentrations exceeding U.S. Environmental Protection Agency beach action value criteria of 235 most probable number	none	Response	CRK NWW
Precip	Median 24-hour antecedent precipitation by season	None	Explanatory	CRK NWW
Forest	Proportion of drainage area with forested land use type	Arcsine-square root	Explanatory	StreamStats
Devel	Proportion of drainage area with developed land use type	Arcsine-square root	Explanatory	StreamStats
Imp	Proportion of drainage area with impervious surface area	Arcsine-square root	Explanatory	StreamStats
Dog park count	Number of dog parks in drainage area	None	Explanatory	This study
Dog park density	Density of dog parks in the drainage area	None	Explanatory	This study
Distance to dog park ^B	Distance to the nearest dog park within the drainage area	None	Explanatory	This study

^A CRK: Chattahoochee River Keeper, <https://nww.chattahoochee.org/DataPage>, accessed May 17, 2022; StreamStats: <https://streamstats.usgs.gov>, accessed May 17, 2022.

^B Only included in Spearman rank correlation analysis.

The USGS StreamStats Application (<https://streamstats.usgs.gov>, accessed May 17, 2022) was used to create shapefiles of the drainage basins for import to ArcMap and to calculate drainage area and percent land use for forested (Forest; Fry et al. 2011), developed (Devel; (Homer et al. 2015)), and impervious surface areas (Imp; Homer et al. 2015). GPS coordinates for CRK NWW sites did not always fall on cells of the drainage network, which is necessary for StreamStats to delineate basins. In these cases, a proximal stream cell was selected when possible (see Appendix B for GPS coordinates from CRK NWW versus StreamStats). Of the 63 CRK NWW sites with *E. coli* data in the CHAT watershed, drainage basins were able to be delimited for 61 (Appendix B), which were used for subsequent analysis. We imported the 61 drainage basin shapefiles into ArcMap to count the number of dog parks in each drainage basin and to calculate dog park density for each site (Appendix B). We also used the “flow length” tool in ArcMap to determine distances from each sample site to the closest dog park in the drainage basin (Appendix B). Drainage basins frequently overlapped (e.g., Peachtree Creek at Ridgewood Rd drainage basin contained 39 sample sites and their associated drainage basins; Appendix B) as determined using the “spatial join” tool in ArcMap, indicating spatial autocorrelation in the data which could artificially inflate statistical significance of explanatory variables (by reducing the confidence interval size; Legendre 1993) and their associations with sites across the watershed.

A total of 3,847 *E. coli* records were available from the 61 CRK NWW sites within the CHAT watershed for which drainage basins could be defined in StreamStats (Figure 1; Appendix B). The number of *E. coli* measurements per site ranged from 1 to 136 (Appendix B) with a mean and median of 63 and 57 measurements per site, respectively. Seven sites had fewer than 10 *E. coli* records. Most sample sites were located east of the Chattahoochee River towards the downstream end of CHAT watershed (Figure 1). Drainage basin areas ranged from 0.2 to 339.3 km² (Appendix B). The number of dog parks per drainage basin ranged from 0 to 14 (Appendix B). Thirty-eight of the 61 sites did not have dog parks within their drainage basin. Dog park density within drainage basins ranged from 0 to 0.7 dog parks per km².

Statistical analysis

McKee et al. (2020) found differences among seasons in levels of dog fecal contamination within the CHAT watershed. Seasonal differences in *E. coli* were tested herein using seasonal median values (Spring: March–May; Summer: June–August; Fall: September–November; Winter: December–February). Two methods were used to investigate seasonal differences: the non-parametric Wilcoxon rank-sum test (Wilcoxon 1945) and the parametric Tukey-Kramer HSD means comparison method (Tukey 1949). Both indicated seasonal differences among median *E. coli* values (see Results), and therefore all subsequent analyses were conducted by season to account for these differences. To minimize the influence of outlier events or concentrations and account for the differences in the number of samples collected and the dates of sample collection, we used seasonal median *E. coli* concentrations and *E. coli* beach action value (BAV) exceedance rates (proportion of samples that exceeded 235 most probable number (MPN) of viable *E. coli* per 100 mL; (U.S. Environmental Protection Agency 2012)) as our response variables for analysis. *E. coli* is one of the fecal indicator organisms the state of Georgia uses to regulate water quality (Georgia Department of Natural Resources 2022). Seasonal median *E. coli* values were log-transformed and land use percentages

were arcsine-square root transformed to linearize the variables for forward stepwise linear regression (Table 1).

We compared levels of our response variables between sites with and without dog parks in the drainage basin using the non-parametric Wilcoxon rank-sum test in JMP (v14.2.0, SAS Institute Inc.). We conducted forward stepwise linear regression in JMP to investigate associations between *E. coli* (median and BAV exceedance rates; Table 1) and explanatory variables (precip, forest, devel, imp, dog park count, and dog park density; Table 1) using the minimum Bayesian information criterion (BIC; (Schwarz 1978)) as the stopping rule. Models with lower BIC scores are generally considered to better fit the data. BIC is used to prevent overfitting models by introducing a penalty to the BIC score for each parameter that is added to the model. Variance inflation factors (VIF) were used to determine models with high levels of collinearity among predictor variables. Among other possible issues, multicollinearity in a model can indicate that the model is unstable and small changes to the data could cause the model to fluctuate (Greene 1993). Models containing variables with VIF values of 10 or greater indicate a high degree of correlation with other variables in the model (Belsley 1991), indicating multiple variables are explaining the same variation. To assess the potential association between *E. coli* and dog park proximity we conducted non-parametric Spearman rank correlations between distance in kilometers to the nearest dog park (distance to dog park; Table 1) within the drainage basin and the dog park metrics. Only sites with dog parks within the drainage basins were used for the correlation analysis between distance to dog park and the dog park metrics. Spearman rank correlations were also conducted between the other dog park metrics and *E. coli* metrics for exploratory purposes. We used $\alpha < 0.05$ to determine statistical significance for all analyses.

Results

Escherichia coli concentrations ranged from 50 to 120,980 MPN/100 mL. Overall median *E. coli* concentrations by site ranged from 50 to 1,475 MPN/100 mL and were generally higher towards the southern end of the CHAT watershed (Figure 2). Seasonal median *E. coli* concentrations were highest in the summer (mean (standard deviation) = 662 (548) MPN/100 mL; Figure 3a). Sixty-five percent of the 3,847 *E. coli* records in the study exceeded the BAV. Three sites with more than one sample had a BAV exceedance rate greater than 90% (North Fork Peachtree Creek at Mary Scott Nature Park, Nancy Creek at Tilly Mill Rd, and CSO at Tanyard Creek; Appendix B). Forty-nine of the 61 study sites (80%) had *E. coli* concentrations that exceeded the BAV for the majority of the records. Seasonal *E. coli* BAV exceedance rates were highest in the summer and fall (mean (standard deviation) = 72% (25%) and 69% (22%), respectively; Figure 3b).

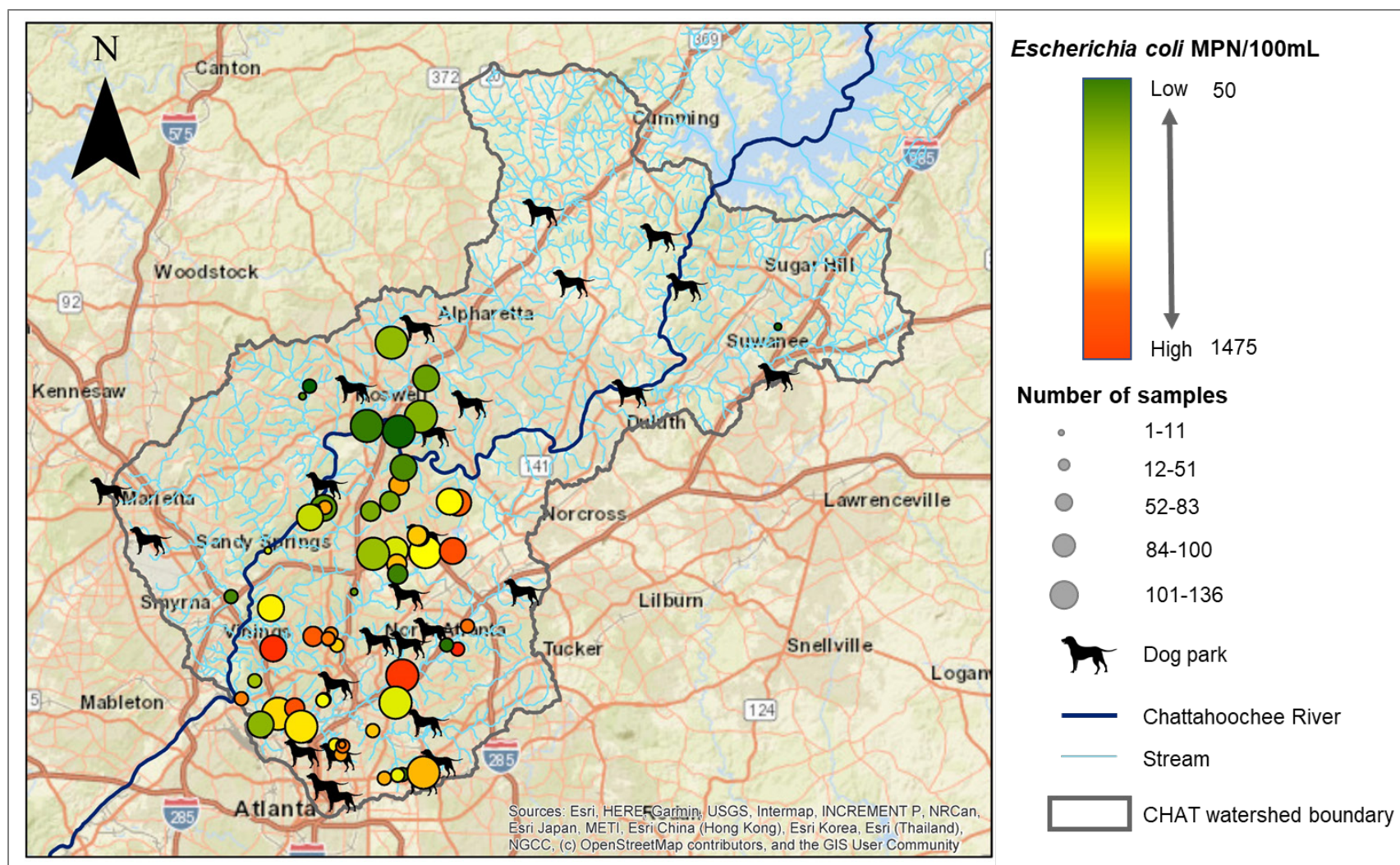


Figure 2. Sample size and median *Escherichia coli* concentrations across study sites.

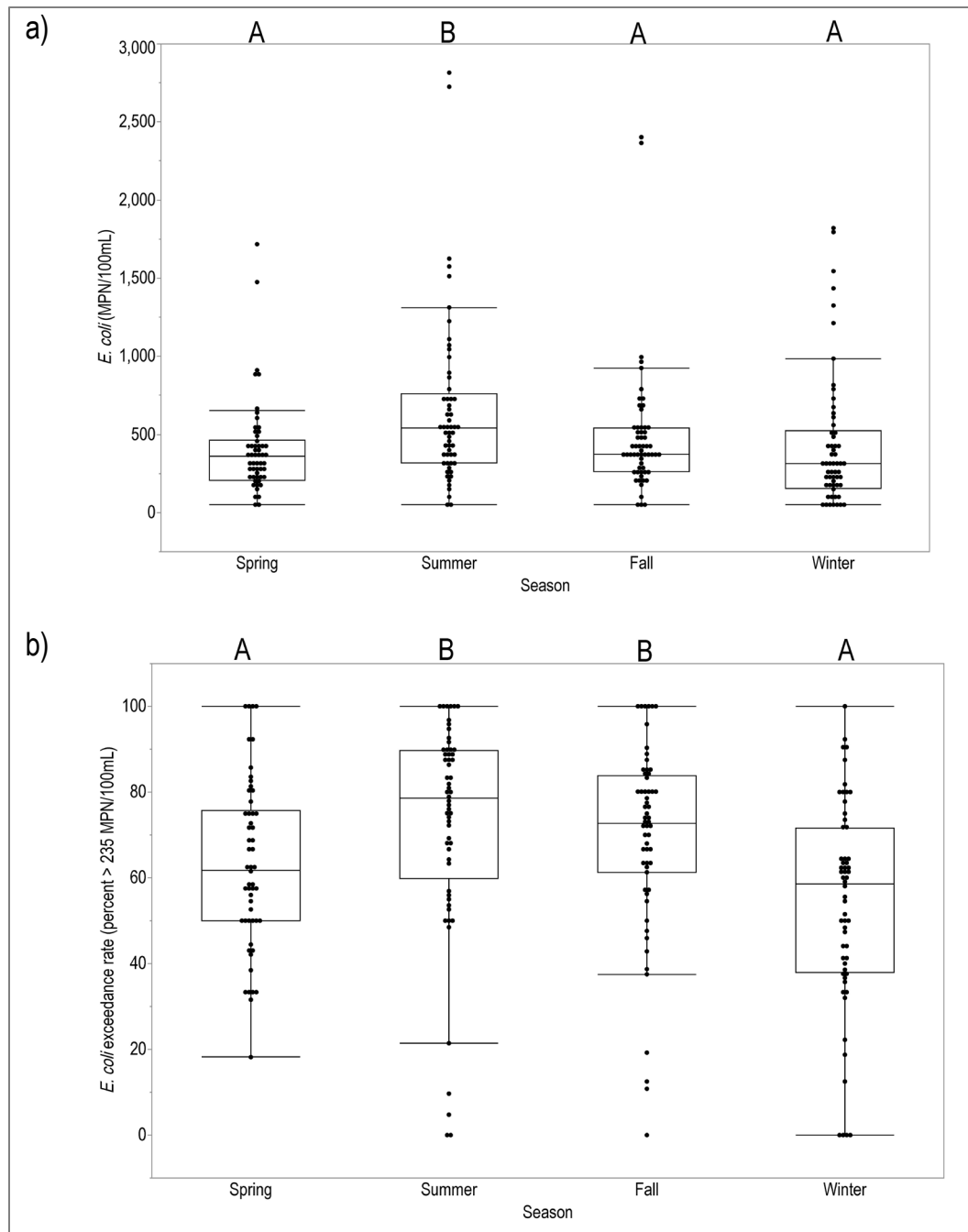


Figure 3. Seasonal *Escherichia coli* (*E. coli*) most probable number (MPN) per 100 milliliter concentration (a) and seasonal *E. coli* beach action value (BAV) exceedance rate (b). The middle line of the box indicates the median value. Lower and upper bounds of the box are the interquartile range (IQR; 25th and 75th quartiles of the data). Whiskers indicate 1.5x the IQR. Points outside the whiskers indicate outlier data. Letters above boxplots indicate statistical differences based on the Wilcoxon rank-sum test, $p < 0.05$.

Results from the Wilcoxon rank-sum tests indicated that there was no difference in the *E. coli* concentrations in the spring or fall between sites with and without dog parks in the drainage basins ($p = 0.195$ and 0.148 , respectively). However, in the summer and winter, sites with dog parks in the

basins had higher *E. coli* concentrations than sites without dog parks in the basins ($p = 0.038$ and $p = 0.034$, respectively). There was no difference in BAV exceedance rates in the spring, summer, or fall between sites with and without dog parks in the drainage basins ($p = 0.267$, 0.298 , and 0.176 , respectively). However, sites with dog parks in the drainage basins had higher rates of BAV exceedance in the winter ($p = 0.018$).

All explanatory variables in the seasonal forward stepwise linear regression models were significant. However, the adjusted R^2 values for all of the seasonal models of *E. coli* concentration were low (0.058 to 0.236 ; Table 2), indicating that the explanatory variables did not explain much of the variability in *E. coli* concentrations. The best models of *E. coli* concentration differed for all seasons; however the spring, summer, and winter models all included Devel (Table 2), which had positive parameter estimates ($\beta = 1.39$, 2.23 , and 1.66 , respectively; Table 2). Dog park count was positively associated with *E. coli* concentrations in the winter ($\beta = 0.14$; Table 2). Adjusted R^2 values for the seasonal models of BAV exceedance rate were also low ($R^2 = 0.058$ to 0.236 ; Table 3). Explanatory variables selected by the forward stepwise linear regression of BAV exceedance rate were similar to explanatory variables in the *E. coli* concentration models; spring and winter models both included Devel with positive associations ($\beta = 0.42$ and 0.51 , respectively; Table 3). Similar to the forward stepwise linear regression results for *E. coli* concentration, the winter model for BAV exceedance rate also included dog park count, which was positively associated with BAV exceedance rate ($\beta = 0.03$; Table 3). Forest was negatively associated with BAV exceedance rate in the summer and fall models ($\beta = -0.67$ and -0.32 , respectively; Table 3). Precip was included in the spring model of *E. coli* concentration and the fall model of BAV exceedance rate, however the directions of association were different for the two models ($\beta = 5.32$ and -0.68 , respectively; Table 2 and Table 3).

Table 2. Forward stepwise linear regression results for seasonal *Escherichia coli* (*E. coli*) concentration (log-transformed seasonal median values). Italicized font indicates statistically significant model terms with $p < 0.05$.

Season	Number of Sites	Adjusted R ²	Bayesian Information Criterion	Term ^A	Parameter Estimate	Standard Error	p	Lower 95%	Upper 95%	Variance Inflation Factor
Spring	54	0.212	113.2	<i>Intercept</i>	4.15	0.57	<.0001	3.00	5.30	–
	–	–	–	<i>Precip</i>	5.32	2.52	0.040	0.25	10.38	1.07
	–	–	–	<i>Devel</i>	1.39	0.50	0.008	0.38	2.40	1.07
Summer	57	0.236	131.3	<i>Intercept</i>	3.67	0.60	<.0001	2.47	4.88	–
	–	–	–	<i>Devel</i>	2.23	0.52	<.0001	1.18	3.27	1
Fall	59	0.058	135.7	<i>Intercept</i>	6.41	0.24	<.0001	5.93	6.88	–
	–	–	–	<i>Forest</i>	–1.11	0.52	0.037	–2.16	–0.07	1
Winter	58	0.199	162.0	<i>Intercept</i>	3.60	0.75	<.0001	2.10	5.11	–
	–	–	–	<i>Dog park count</i>	0.14	0.05	0.004	0.05	0.23	1.00
	–	–	–	<i>Devel</i>	1.66	0.65	0.014	0.34	2.97	1.00

^A Intercept, the mean value of the response variable when the explanatory variables in the model are equal to zero; Precip, seasonal median 24-hour antecedent precipitation; Devel: arcsine-square root transformed percent of drainage area that has been developed; Forest: arcsine-square root transformed percent of drainage area that is forested.

Table 3. Forward stepwise linear regression results for seasonal *E. coli* beach action value (U.S. Environmental Protection Agency 2012) exceedance rate (percent of samples with *E. coli* concentrations >235 most probable number per 100 milliliters). Italicized font indicates statistically significant model terms with $p < 0.05$.

Season	Number of Sites	Adjusted R ²	Bayesian Information Criterion	Term ^A	Parameter Estimate	Standard Error	p	Lower 95%	Upper 95%	Variance Inflation Factor
Spring	54	0.119	-18.8	Intercept	0.15	0.17	0.374	-0.19	0.49	–
	–	–	–	<i>Devel</i>	<i>0.42</i>	<i>0.15</i>	<i>0.006</i>	<i>0.12</i>	<i>0.71</i>	<i>1</i>
Summer	57	0.204	2.4	<i>Intercept</i>	<i>1.00</i>	<i>0.08</i>	<i><.0001</i>	<i>0.85</i>	<i>1.16</i>	–
	–	–	–	<i>Forest</i>	<i>-0.67</i>	<i>0.17</i>	<i><0.001</i>	<i>-1.01</i>	<i>-0.33</i>	<i>1</i>
Fall	59	0.190	-8.8	<i>Intercept</i>	<i>0.84</i>	<i>0.07</i>	<i><.0001</i>	<i>0.70</i>	<i>0.98</i>	–
	–	–	–	<i>Precip</i>	<i>-0.68</i>	<i>0.18</i>	<i>0.001</i>	<i>-1.05</i>	<i>-0.31</i>	<i>1.05</i>
	–	–	–	<i>Forest</i>	<i>-0.32</i>	<i>0.15</i>	<i>0.039</i>	<i>-0.63</i>	<i>-0.02</i>	<i>1.05</i>
Winter	58	0.242	-3.4	Intercept	-0.08	0.18	0.663	-0.44	0.28	–
	–	–	–	<i>Dog park count</i>	<i>0.03</i>	<i>0.01</i>	<i>0.005</i>	<i>0.01</i>	<i>0.05</i>	<i>1.00</i>
	–	–	–	<i>Devel</i>	<i>0.51</i>	<i>0.16</i>	<i>0.002</i>	<i>0.19</i>	<i>0.82</i>	<i>1.00</i>

^A Intercept, the mean value of the response variable when the explanatory variables in the model are equal to zero; Precip, seasonal median 24-hour antecedent precipitation; Devel: arcsine-square root transformed percent of drainage area that has been developed; Forest: arcsine-square root transformed percent of drainage area that is forested.

Spearman rank correlations between seasonal *E. coli* metrics (*E. coli* concentration and BAV exceedance rate) and dog park metrics indicated that dog park count was the dog park metric most frequently associated with *E. coli* metrics. Dog park count was positively correlated with *E. coli* concentration in the summer and winter (Spearman $\rho = 0.2678$ and 0.3277 , respectively; Table 4) and with BAV exceedance rate in the winter (Spearman $\rho = 0.3493$, Table 5). Distance to dog park was negatively correlated with *E. coli* concentration in the winter (Spearman $\rho = -0.6182$, Table 4), indicating that sites with a dog park in close proximity in the drainage basin had higher median *E. coli* concentrations in the winter than sites for which the nearest dog park in the drainage basin was further away. Dog park density was also positively correlated with BAV exceedance in the winter (Spearman $\rho = 0.2641$, Table 5).

Table 4. Spearman rank correlations (ρ) between *Escherichia coli* concentration (log-transformed seasonal median values) and dog park metrics. Italicized font indicates statistically significant model terms with $p < 0.05$.

Season	Number of Sites	Term	Spearman ρ	p
Spring	54	Dog park count	0.1724	0.213
	54	Dog park density	0.0827	0.552
	22	Distance to dog park	-0.3945	0.069
Summer	57	<i>Dog park count</i>	<i>0.2678</i>	<i>0.044</i>
	57	Dog park density	0.1603	0.234
	23	<i>Distance to dog park</i>	<i>-0.6182</i>	<i>0.002</i>
Fall	59	Dog park count	0.2266	0.084
	59	Dog park density	0.1974	0.134
	23	Distance to dog park	0.2447	0.260
Winter	58	<i>Dog park count</i>	<i>0.3277</i>	<i>0.012</i>
	58	Dog park density	0.2178	0.101
	22	Distance to dog park	-0.0701	0.757

Table 5. Spearman rank correlations (ρ) between *Escherichia coli* beach action value exceedance rate (percentage of samples exceeding the U.S. Environmental Protection Agency beach action value of 235 most probable number per 100 milliliters) and dog park metrics. Italicized font indicates statistically significant model terms with $p < 0.05$.

Season	Number of Sites	Term	Spearman ρ	p
Spring	54	Dog park count	0.1476	0.287
	54	Dog park density	0.0618	0.657
	22	Distance to dog park	-0.3372	0.125
Summer	57	Dog park count	0.1192	0.377
	57	Dog park density	0.0723	0.593
	23	Distance to dog park	-0.3829	0.071
Fall	59	Dog park count	0.1556	0.239
	59	Dog park density	0.1553	0.240
	23	Distance to dog park	-0.0874	0.692
Winter	58	<i>Dog park count</i>	<i>0.3493</i>	<i>0.007</i>
	58	<i>Dog park density</i>	<i>0.2641</i>	<i>0.045</i>
	22	Distance to dog park	0.052	0.818

Discussion

This study provided support for the hypothesis that dog parks are a source of fecal contamination in surface waters within the CHAT watershed, particularly in the summer and winter. *Escherichia coli* concentrations were higher in the summer and winter, and BAV exceedance rates were higher in the winter, at sites with dog parks in the drainage basins. Forward stepwise linear regression models indicated *E. coli* concentrations and BAV exceedance rates increased with an increasing number of dog parks within the drainage basins. Higher numbers of dog parks within the drainage basins were associated with higher *E. coli* concentrations in the summer and winter as well as with higher BAV exceedance rates in the winter. For sites with dog parks within the drainage basins, *E. coli* concentrations were higher in the summer for sites where the nearest dog park was more proximal than for sites where the nearest dog park was more distant. Additionally, sites with higher densities of dog parks within the drainage basins had more frequent rates of BAV exceedance in the winter than those with lower densities of dog parks. The seasonal differences could be caused by a number of factors, including changes in hydrologic conditions across seasons (e.g., more stormwater runoff in the winter) and seasonal changes in peoples' behavior (e.g., more people walking their dogs in the summer). However, spatial autocorrelation of the variables increases the risk of falsely detecting a significant relationship between an explanatory and response variable. A post-hoc analysis indicated the number of dog parks within a drainage basin was strongly correlated with the number of additional sites nested within the drainage basin ($R^2 = 0.74$), demonstrating the dog park count metric was prone to issues with spatial autocorrelation.

Another limitation to this study is the use of *E. coli* as an indicator of levels of dog fecal contamination. *Escherichia coli* occurs in the intestinal tracts of many species, including humans and other warm-blooded animals. Our decision to use *E. coli* to represent levels of fecal contamination across our study sites was based on data availability and the fact that *E. coli* was recently adopted in Georgia as the regulatory constituent for assessing levels of fecal-associated bacteria in waters with designated uses and differentiated by season (Georgia Department of Natural Resources 2022). McKee et al. (2020) found that *E. coli* in the Chattahoochee River was correlated with levels of a dog fecal genetic marker and found that *E. coli* was more strongly correlated with that dog fecal marker than the human or ruminant fecal genetic markers. The findings suggested dogs were a primary source of fecal contamination in the Chattahoochee River over the duration of the McKee et al. (2020) study. Differences in study sites and study timeline between McKee et al. (2020) and the current study prevent the assumption of similar patterns. It is possible that dog parks are not primary sources of dog fecal contamination in waterways across the metropolitan Atlanta area in the CHAT watershed. Tambalo et al. (2012) did not detect dog fecal contamination in water samples from dog parks in Alberta, Canada, suggesting dog parks were not primary sources of fecal contamination in nearby waters.

The list of dog parks compiled for our study were limited to enclosed off-leash dog parks. Blenderman et al. (2018) found that dog owners at off-leash parks were less likely to pick up their dog's waste than owners at on-leash dog parks, as determined by direct observations. Riedel et al. (2015) also suggested that social pressure from other visitors could modify dog owner behavior with

regards to cleaning up dog waste. Dog owner behavior therefore may have differed across dog parks based on perceived social pressure by the presence of other visitors (Riedel et al. 2015). If social pressures do affect dog owner behavior and owners are more likely to pick up after their dogs when more people were around, then the effect of an increase in the number of dogs on levels of fecal contamination may have been offset to some extent by more owners picking up after their dogs because of social pressures.

Forward stepwise linear regression models of *E. coli* concentrations and *E. coli* exceedances above the BAV suggested that *E. coli* concentration and *E. coli* exceedance rates increased with the proportion of development within the drainage area, although no distinction was made between commercial versus residential development. Increased development could be indicative of higher densities of human waste-management strategies, such as septic systems and sewer lines, thereby suggesting humans could be a primary source of fecal contamination across our study sites. However, yard-based dog waste is another source that could be explored in the watershed. According to the American Veterinary Medical Association, 38.4% of households in the United States have dogs as pets (<https://www.avma.org/resources-tools/reports-statistics/us-pet-ownership-statistics>, accessed Nov 23, 2021). High housing density can be associated with high per area rates of pet ownership (Hobbie et al. 2017), which if applicable to the metro-Atlanta area, is one possible explanation for the positive association between development within the watershed and *E. coli* levels.

Pet waste from households has been found to contribute high levels of nutrient contamination to the watershed. Fissore et al. (2012) found that pet waste accounted for 84% of the phosphorous input from the residential landscape across 360 single-family residences in the St. Paul-Minneapolis metropolitan area. Hobbie et al. (2017) also found that pet waste from households contributed up to 76% of the phosphorous inputs to the watershed nutrient budget in subwatersheds of the Mississippi River in St. Paul, Minnesota, much of which was exported from the watershed in stormwater runoff. Efforts to reduce pet waste generally focus on public areas. However, reducing dog fecal contamination to waterways from stormwater may require the prompt cleanup of pet waste from yards (Hobbie et al. 2017).

More than 60% of the *E. coli* records used for this study exceeded the BAV, suggesting a high frequency of water quality conditions indicative of an elevated human health risk at the study sites. Similarly frequent BAV exceedance rates (62.5 to 100 percent) were estimated at 15 surface water sites—some of which are located on tributaries to CHAT—throughout DeKalb County, Georgia between 2012 and 2016 (Aulenbach et al. 2022). Dog waste can be a source of zoonotic pathogens, such as pathogenic *E. coli*, *Giardia*, *Salmonella*, and *Cryptosporidium* (Krauss et al. 2003). Explaining the connection between human health and dog waste may be one effective approach for outreach efforts. Lowe et al. (2014) found that the belief by dog walkers that picking up dog waste was the “right thing to do” was associated with awareness of the health risks. Ervin et al. (2014) found that dogs were primary sources of fecal contamination in coastal lagoon waters that came from residences along an upstream creek. Levels of dog contamination in the coastal lagoon decreased after a door-to-door outreach campaign at creek-side homes with dogs, which focused on proper pet waste disposal (Ervin et al. 2014). Together, these studies suggest that if specific neighborhoods or

residences with dogs are determined to be sources of fecal contamination in the CHAT watershed, a targeted campaign towards residences with dog owners may be effective for a change in behavior regarding picking up dog waste. Future studies to determine source locations of dog fecal contamination may benefit from using dog-specific genetic markers for samples from tributaries to differentiate contamination from other sources.

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Appendix A

Dog parks in the Atlanta, Georgia metropolitan area

Table 6. List of dog parks in the Atlanta, Georgia Metropolitan Area.

Name	Address	City	County	Within CHAT Watershed ^A	Management	Source
Chattapoochee Dog Park	4291 Rogers Bridge Road	Duluth	Gwinnett	Yes	City of Duluth	City of Duluth (2020)
Settles Bridge Park	380 Johnson Road	Suwanee	Gwinnett	Yes	Gwinnett County	Gwinnett County Government (2021)
Alexander Park	800 Old Snellville Highway	Lawrenceville	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
Ronald Reagan Park	2777 Five Forks Trickum Road SW	Lawrenceville	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
Rock Springs Park	310 Old Peachtree Road NE	Suwanee	Gwinnett	Yes	Gwinnett County	Gwinnett County Government (2021)
Rabbit Hill Park	400 Rabbit Hill Road	Dacula	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
J.B. Williams Park	4935 Five Forks-Trickum Road SW	Lilburn	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
Pinckneyville Park	4758 South Old Peachtree Road	Norcross	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
Graves Park	1540 Graves Road	Norcross	Gwinnett	Yes	Gwinnett County	Gwinnett County Government (2021)
Harbins Park	2995 Luke Edwards Road	Dacula	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)

^A Chattahoochee River National Recreation Area

Table 6 (continued). List of dog parks in the Atlanta, Georgia Metropolitan Area.

Name	Address	City	County	Within CHAT Watershed ^A	Management	Source
Lenora Park	4515 Lenora Church Road	Snellville	Gwinnett	No	Gwinnett County	Gwinnett County Government (2021)
Caney Creek Preserve	2755 Caney Road	Cumming	Forsyth	Yes	Forsyth County	Forsyth County Government (2021)
Coal Mountain Dog Park	4060 County Way	Cumming	Forsyth	No	Forsyth County	Forsyth County Government (2021)
Fowler Park	4110 Carolene Way	Cumming	Forsyth	Yes	Forsyth County	Forsyth County Government (2021)
Windermere Park	3355 Windermere Parkway	Cumming	Forsyth	Yes	Forsyth County	Forsyth County Government (2021)
Pitner Road Dog Park	2450 Pitner Road NW	Acworth	Cobb	No	Cobb County	Cobb County Government (undated)
Sweat Mountain Park	4346 Steinhauer Road	Marietta	Cobb	No	Cobb County	Cobb County Government (undated)
Sweetwater Park	2447 Clay Road SW	Austell	Cobb	No	Cobb County	Cobb County Government (undated)
Canine Crossing Dog Park	4951 Camp Drive	Atlanta	Fulton	No	City of South Fulton	City of South Fulton (undated)
Piedmont Park	400 Park Drive NE	Atlanta	Fulton	Yes	City of Atlanta	City of Atlanta, GA (undated)
South Bend Dog Park	1955 Compton Drive SE	Atlanta	Fulton	No	City of Atlanta	City of Atlanta, GA (undated)
Renaissance Park	501 Piedmont Avenue NE	Atlanta	Fulton	Yes	City of Atlanta	City of Atlanta, GA (undated)

^A Chattahoochee River National Recreation Area

Table 6 (continued). List of dog parks in the Atlanta, Georgia Metropolitan Area.

Name	Address	City	County	Within CHAT Watershed ^A	Management	Source
Walker Park	200 Memorial Terrace SE	Atlanta	Fulton	No	City of Atlanta	City of Atlanta, GA (undated)
Freedom Barkway/Freedom Park	523 Highland Avenue NE	Atlanta	Fulton	Yes	City of Atlanta	City of Atlanta, GA (undated)
Kirkwood Dog Park	1694 Wade Avenue NE	Atlanta	Fulton	No	City of Atlanta	City of Atlanta, GA (undated)
Park Grounds	142 Flat Shoals Avenue SE	Atlanta	Fulton	No	Park Grounds	Park Grounds (undated)
Woofstock Dog Park	150 Dupree Road	Woodstock	Cherokee	No	City of Woodstock	City of Woodstock (undated)
Newtown Dream Dog Park	3150 Old Alabama Road	Johns Creek	Fulton	Yes	City of Johns Creek	City of Johns Creek (2021)
Morgan Falls River Park	100 Morgan Falls Road	Sandy Springs	Fulton	Yes	City Sandy Springs	City of Sandy Springs (undated)
Waggy World Paw Park (Wills Park)	175 Roswell Street	Alpharetta	Fulton	Yes	City of Alpharetta	City of Alpharetta (undated)
Brook Run Dog Park	4770 North Peachtree Road	Dunwoody	Dekalb	Yes	City of Dunwoody	Discover Dunwoody (undated)
Leita Thompson Dog Park	1355 Woodstock Road	Roswell	Fulton	Yes	City of Roswell	Roswell, Georgia (2021)
Woodstock Soccer Complex	40 Woodstock Road	Roswell	Fulton	Yes	City of Roswell	Roswell, Georgia (2021)
East Roswell Park	9000 Fouts Road	Roswell	Fulton	Yes	City of Roswell	Roswell, Georgia (2021)

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Table 6 (continued). List of dog parks in the Atlanta, Georgia Metropolitan Area.

Name	Address	City	County	Within CHAT Watershed ^A	Management	Source
Mason Mill Park	1340 McConnell Drive	Decatur	Dekalb	Yes	DeKalb County	Dekalb County Georgia (2019)
Glenlake Dog Park	1121 Church Street	Decatur	Dekalb	Yes	City of Decatur	City of Decatur (undated)
Oakhurst Dog Park	450 East Lake Drive	Decatur	Dekalb	No	City of Decatur	City of Decatur (undated)
Adair Dog Park	600 W Trinity Place	Decatur	Dekalb	Yes	City of Decatur	City of Decatur (undated)
Wildwood Park	1050 Barclay Circle	Marietta	Cobb	Yes	City of Marietta	City of Marietta (undated)
Lewis Park	475 Campbell Hill Street NW	Marietta	Cobb	Yes	City of Marietta	City of Marietta (undated)
Atlantic Station Dog Park	State Street NW and 17th Street NW	Atlanta	Fulton	Yes	Atlantic Station	Wag! (2021)
Brookside Park	3661 N Decatur Road	Decatur	Dekalb	No	DeKalb County	Dekalb County Georgia (2017)
Milam Park/Clarkston Dog Park	3867 Norman Road	Clarkston	Dekalb	No	City of Clarkston	City of Clarkston (2018)
Fetch Park	520 Daniel Street SE	Atlanta	Fulton	No	Fetch Park	Fetch (undated)
Railside Dog Park	210 Peters Street SW	Atlanta	Fulton	No	Castleberry Hill Neighborhood Association	Bring Fido (2021)
Burger Park	680 Glendale Place	Smyrna	Cobb	No	City of Smyrna	City of Smyrna (2021)
Lake Court Park	3500 Lake Drive SE	Smyrna	Cobb	No	City of Smyrna	City of Smyrna (2021)
Swift-Cantrell Park	3140 Old 41 Highway NW	Kennesaw	Cobb	No	City of Kennesaw	City of Kennesaw (2021)
Frankie Allen Park	425 Pharr Road NE	Atlanta	Fulton	Yes	City of Atlanta	Buckhead Community (undated)

^A Chattahoochee River National Recreation Area

Table 6 (continued). List of dog parks in the Atlanta, Georgia Metropolitan Area.

Name	Address	City	County	Within CHAT Watershed ^A	Management	Source
Skyland Dog Park	2600 Skyland Drive NE	Brookhaven	Dekalb	Yes	City of Brookhaven	City of Brookhaven (undated)
Brookhaven Park	4158 Peachtree Road NE	Brookhaven	Dekalb	Yes	City of Brookhaven	City of Brookhaven (undated)
Oak Road Neighborhood Park	1925 Oak Road SW	Snellville	Gwinnett	No	City of Snellville	City of Snellville (undated)
Arrow Creek Park	4445 Buford Highway NE	Chamblee	Dekalb	Yes	City of Chamblee	City of Chamblee (2021)
Keswick Park	3496 Keswick Drive	Chamblee	Dekalb	Yes	City of Chamblee	City of Chamblee (2021)

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Appendix B

Table 7. Study site GPS coordinates and site characteristics. Abbreviations: CRK NWW, Chattahoochee Riverkeeper Neighborhood Waterwatch; Lat, Latitude; Long, Longitude; km, kilometer; N, number of *Escherichia coli* samples; Devel, Developed; Imp, Impervious surface; N/A, not applicable.

Map #	CRK NWW site name	Short name	CRK NWW Lat	CRK NWW Long	Stream stats Lat	Stream stats Long	Drainage basin area (km ²)	N	Forest (%)	Devel (%)	Imp (%)	Dog park count	Nearest dog park (km)
1	Nancy Creek at Roswell Rd	Nanc @ Rosw	33.866148	-84.380912	33.866148	-84.380912	72.8	33	18	82	30	3	5.27
2	Tanyard Creek in Tanyard Creek Park	Tany @ Park	33.8081	-84.4022	33.8081	-84.4022	11	134	2	98	62	1	3.28
3	PHENA Duck Pond West	DucW @ Pond	33.825384	-84.385046	33.825384	-84.385046	0.4	46	7	93	34	0	N/A
4	Woodall Creek at Collier	Wood @ Coll	33.809497	-84.434572	33.809497	-84.434572	4.8	85	6	93	64	0	N/A
5	Nancy Creek at Randall Mill Rd	Nanc @ Rand	33.8597	-84.424437	33.8597	-84.424437	90.4	94	23	77	27	3	10.85
6	Peachtree Creek at Northside Drive	Peac @ Nside	33.82028	-84.407499	33.82028	-84.407499	223	66	16	84	33	11	5.34
7	Beaverbrook Park	Beav @ Park	33.816536	-84.420681	33.816536	-84.420681	1.6	131	7	93	33	0	N/A
8	Nancy Creek at West Wesley Rd	Nanc @ WWes	33.838381	-84.439248	33.838381	-84.439248	97.6	50	24	76	26	3	15.26
9	Mill Creek at Land O Lakes	Mill @ Land	33.861725	-84.373975	33.861725	-84.373975	3	32	21	82	37	0	N/A
10	Mill Creek at Nancy Creek	Mill @ Nanc	33.86592	-84.38045	33.86592	-84.38045	3.5	30	22	80	34	0	N/A

Table 7 (continued). Study site GPS coordinates and site characteristics. Abbreviations: CRK NWW, Chattahoochee Riverkeeper Neighborhood Waterwatch; Lat, Latitude; Long, Longitude; km, kilometer; N, number of *Escherichia coli* samples; Devel, Developed; Imp, Impervious surface; N/A, not applicable.

Map #	CRK NWW site name	Short name	CRK NWW Lat	CRK NWW Long	Stream stats Lat	Stream stats Long	Drainage basin area (km ²)	N	Forest (%)	Devel (%)	Imp (%)	Dog park count	Nearest dog park (km)
11	North Fork Nancy Creek above Murphy Candler Lake	Nanc @ Murp	33.915352	-84.326263	33.915352	-84.326263	4.8	76	15	84	32	0	N/A
12	Big Creek at Riverside Park	BigC @ Rive	34.006291	-84.350204	34.006291	-84.350204	269.4	112	29	62	20	5	7.07
13	Marsh Creek at Riverside Dr	Mars @ Rive	33.946043	-84.395207	33.946043	-84.395207	14.5	100	23	77	24	0	N/A
14	Rottenwood Creek at Bob Callan Trail	Rott @ BobC	33.893906	-84.457921	33.893906	-84.457921	48.2	51	11	89	40	1	10.83
15	Heards Creek at River Chase Circle	Hear @ Rive	33.924339	-84.428653	33.924339	-84.428653	2.2	8	41	59	9	0	N/A
16	Clear Creek at Daylight Tunnel in Piedmont Park	Clea @ Dayl	33.78968	-84.370882	33.78968	-84.370882	11.9	34	1	99	56	3	0.22
17	Peachtree Creek at Ridgewood Rd	Peac @ Ridg	33.826519	-84.449747	33.826519	-84.449747	339.3	49	19	81	30	14	11.93
18	Long Island Creek at Northside Drive	Long @ Nside	33.886195	-84.42644	33.886195	-84.42644	15.9	98	38	63	18	0	N/A
19	Falling Branches at Riverside	Fall @ Rive	33.952283	-84.390043	33.952283	-84.390043	0.5	1	38	61	8	0	N/A
20	Nancy Creek at Rickenbacker Dr	Nanc @ Rick	33.869231	-84.378566	33.869231	-84.378566	68.9	31	18	82	30	3	4.82
21	PHENA Duck Pond East	DucE @ Pond	33.825906	-84.384223	33.825906	-84.384223	0.3	42	8	92	32	0	N/A

Table 7 (continued). Study site GPS coordinates and site characteristics. Abbreviations: CRK NWW, Chattahoochee Riverkeeper Neighborhood Waterwatch; Lat, Latitude; Long, Longitude; km, kilometer; N, number of *Escherichia coli* samples; Devel, Developed; Imp, Impervious surface; N/A, not applicable.

Map #	CRK NWW site name	Short name	CRK NWW Lat	CRK NWW Long	Stream stats Lat	Stream stats Long	Drainage basin area (km ²)	N	Forest (%)	Devel (%)	Imp (%)	Dog park count	Nearest dog park (km)
22	Tanyard Algae Pipe at The Reserve	TanT @ Alga	33.80197	-84.401096	33.80197	-84.401096	10	32	1	99	64	1	2.47
23	Falling Branches at Brandon Mill	Fall @ Bran	33.952178	-84.384535	33.952178	-84.384535	0.3	100	29	69	11	0	N/A
24	Big Creek at Big Creek Park	BigC @ Park	34.037469	-84.303087	34.037469	-84.303087	215.2	86	30	59	19	3	5.3
25	Lullwater Creek at Wildwood	Lull @ Wild	33.775925	-84.325569	33.775925	-84.325569	2	29	32	67	13	0	N/A
26	Woodall Creek at Chattahoochee Ave NW	Wood @ Chat	33.80281	-84.431643	33.80281	-84.431643	3.1	3	7	92	61	0	N/A
27	Seven Branches at Martin Rd	Seve @ Mart	34.012424	-84.30728	34.012424	-84.30728	1	110	11	89	43	0	N/A
28	Ball Mill Creek at Spalding	Ball @ Spal	33.978694	-84.321018	33.978694	-84.321018	8.5	96	26	72	16	0	N/A
29	CSO at Tanyard Creek	CSO @ Tany	33.800018	-84.39655	33.800018	-84.39655	8.1	11	1	99	69	1	1.94
30	Foe Killer at Hembree Rd	FoeK @ Hemb	34.061122	-84.330543	34.061122	-84.330543	19.8	116	22	74	20	1	4.38
31	Marsh Creek at Winding Branch (WASS)	Mars @ Wind	33.950011	-84.34721	33.950011	-84.34721	1.1	57	21	79	21	0	N/A
32	Nancy Creek at Ridgeview Park	Nanc @ Ridge	33.89708	-84.360148	33.89708	-84.360148	1.1	1	16	84	32	0	N/A

Table 7 (continued). Study site GPS coordinates and site characteristics. Abbreviations: CRK NWW, Chattahoochee Riverkeeper Neighborhood Waterwatch; Lat, Latitude; Long, Longitude; km, kilometer; N, number of *Escherichia coli* samples; Devel, Developed; Imp, Impervious surface; N/A, not applicable.

Map #	CRK NWW site name	Short name	CRK NWW Lat	CRK NWW Long	Stream stats Lat	Stream stats Long	Drainage basin area (km ²)	N	Forest (%)	Devel (%)	Imp (%)	Dog park count	Nearest dog park (km)
33	Peavine Tributary at Tanyard Garden	Peav @ Tany	33.777772	-84.305197	33.777772	-84.305197	1.3	136	2	98	51	1	0.96
34	Fernbank Creek at Fernbank Forest	Fern @ Fore	33.776458	-84.322044	33.776458	-84.322044	0.2	28	79	23	4	0	N/A
35	Ansley Stream at Maddox Drive	Ansl @ Madd	33.795934	-84.375291	33.795934	-84.375291	0.7	35	8	91	28	0	N/A
36	Ball Mill Creek at Dunwoody Club Dr	Ball @ Dunw	33.967192	-84.324616	33.967192	-84.324616	6.9	75	23	76	17	0	N/A
37	Clear Creek at Monroe Dr	Clea @ Monr	33.795177	-84.369183	33.795177	-84.369183	13.9	32	3	97	51	3	0.98
38	Dunwoody Club Creek at Dunwoody Club Dr	Dunw @ Dunw	33.955682	-84.277653	33.955682	-84.277653	2	87	15	83	23	0	N/A
39	Falling Branches at Dunhill Ct	Fall @ Dunh	33.952582	-84.383238	33.952582	-84.383238	0.2	28	31	67	11	0	N/A
40	Kingsley Lake Creek at Dunwoody Club Dr	King @ Dunw	33.95636	-84.284368	33.95636	-84.284368	4.3	97	15	84	21	0	N/A
41	Lullwater Creek at Ponce de Leon	Lull @ Ponc	33.773945	-84.336149	33.773945	-84.336149	2.5	23	7	93	25	0	N/A
42	Nancy Creek at Village Mill	Nanc @ Vill	33.934069	-84.310052	33.934069	-84.310052	2.5	83	18	79	18	0	N/A
43	Nancy Creek at Perimeter Center Marta	Nanc @ Peri	33.922184	-84.345166	33.922184	-84.345166	2.2	124	4	96	58	0	N/A

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Map #	CRK NWW site name	Short name	CRK NWW Lat	CRK NWW Long	Stream stats Lat	Stream stats Long	Drainage basin area (km ²)	N	Forest (%)	Devel (%)	Imp (%)	Dog park count	Nearest dog park (km)
44	Nancy Creek at Powers Ferry Rd	Nanc @ Powe	33.867693	-84.392888	33.867693	-84.392888	77.4	79	19	81	29	3	6.75
45	Nancy Creek at Tilly Mill Rd	Nanc @ Till	33.923945	-84.281919	33.923945	-84.281919	5.7	94	10	90	42	0	N/A
46	Nancy Creek at W Nancy Creek Dr	Nanc @ WNan	33.908751	-84.325552	33.908751	-84.325552	6.3	76	18	81	28	0	N/A
47	Nancy Creek Fork at Georgetown	Nanc @ Geor	33.924437	-84.327778	33.924437	-84.327778	3	85	16	83	31	0	N/A
48	Nancy Creek Tributary at Peachford Rd	Nanc @ Peac	33.923293	-84.303832	33.923293	-84.303832	7.5	112	17	82	25	1	1.34
49	Nancy Creek Tributary at Peeler Rd	Nanc @ Peel	33.933813	-84.308385	33.933813	-84.308385	2.6	82	18	79	18	0	N/A
50	North Fork Peachtree at Briarwood Rd	PeaN @ Bria	33.841751	-84.321929	33.841751	-84.321929	82.4	119	16	83	32	3	3.38
51	North Fork Peachtree Creek at Flowers Rd	PeaN @ Flow	33.874433	-84.270239	33.874433	-84.270239	29.8	34	10	89	44	1	6.86
52	North Fork Peachtree Creek at Kittredge Park Rd	PeaN @ Kitt	33.823943	-84.32737	33.823943	-84.32737	1	110	24	76	15	0	N/A
53	North Fork Peachtree Creek at Mary Scott Nature Park	PeaN @ Mary	33.859328	-84.277993	33.859328	-84.277993	0.4	35	26	74	9	0	N/A

Table 7 (continued). Study site GPS coordinates and site characteristics. Abbreviations: CRK NWW, Chattahoochee Riverkeeper Neighborhood Waterwatch; Lat, Latitude; Long, Longitude; km, kilometer; N, number of *Escherichia coli* samples; Devel, Developed; Imp, Impervious surface; N/A, not applicable.

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54	North Fork Peachtree Creek at Shallowford Rd	PeaN @ Shal	33.861972	-84.286794	33.861972	-84.286794	49.5	29	15	84	35	1	9.44
55	Pine Grove Lake at Willeo Creek	Pine @ Lake	34.032497	-84.395637	34.032497	-84.395637	0.4	48	44	55	5	0	N/A
56	Seven Branches at Martin Lake Spillway	Seve @ Spill	34.002484	-84.324701	34.002484	-84.324701	7.7	122	22	79	22	0	N/A
57	South Peachtree Creek at Zonolite Park	PeaS @ Zono	-33.805391	84.345401	-33.805391	84.345401	72.5	38	20	80	26	3	6.96
58	Suwanee Creek at Woodward Mill Rd	Suwan @ Woodw	34.071607	-84.023509	34.071607	-84.023509	37	2	36	61	22	0	N/A
59	Wildcat Creek at Dunwoody Nature Center	Wild @ Park	33.956495	-84.331947	33.956495	-84.331947	0.9	75	18	82	32	0	N/A
60	Willeo Creek at Shallowford Rd	Will @ Shall	34.025894	-84.401226	34.025894	-84.401226	21.5	8	32	67	14	0	N/A
61	Clear Creek at Piedmont Ave	Clea @ Pied	33.796159	-84.369799	33.796159	-84.369799	13.9	7	3	97	51	3	1.12

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