Landscape composition does not predict local American crow (*Corvus brachyrhynchos*) abundance in Ottawa, Canada

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Abstract

Urbanisation can impact species distribution by altering landscape characteristics and removing suitable habitat. Consequently, many species are limited to natural habitat fragments. The American crow (*Corvus brachyrhynchos*), however, is successful in urban areas and this could be attributed to their ecological flexibility. Ecological flexibility may allow species to occupy habitats otherwise unfit for non-flexible species. I tested the hypothesis that landscape composition impacts the abundance of ecologically flexible species, such as American crows, but that these species respond positively to urban areas. I predicted there would be more crows in areas with more urban land cover. From repeated visual surveys of 32 sites across Ottawa, Ontario, Canada, I found that landscape composition did not predict local crow abundance. Though these results highlight ecological flexibility in crows, it is important to further investigate the mechanisms behind dispersal given that crows host numerous diseases and frequently inhabit urban areas.

***Keywords**:* urbanisation, American crow, ecological flexibility, habitat

Résumé

L’urbanisation peut affecter la distribution des espèces en changeant les caractéristiques de l’habitat et en enlevant l’habitat convenable. Conséquemment, plusieurs espèces sont limités à des fragments d’habitats naturels. Cependant, le corbeau américain (*Corvus brachyrhynchos*) réussit dans les habitats urbains et ceci peut être attribué à leur flexibilité écologique. La flexibilité écologique peut permettre aux espèces d’occuper des habitats autrement inadaptés aux espèces non flexibles. J’ai testé l’hypothèse que la composition du paysage impacte l’abondance des espèces écologiquement flexibles, comme le corbeau américain, mais que ces espèces répondent positivement aux zones urbaines. J’ai prédit qu’il y aurait plus de corbeaux dans les zones plus urbaines. À partir d’observations visuelles de 32 zones dans la ville d’Ottawa, j’ai constaté que la composition du paysage n’a pas prédit l’abondance locale des corbeaux. Bien que ces résultats mettent en évidence la flexibilité écologique des corbeaux, il est important d’étudier davantage les mécanismes de dispersion étant donné que les corbeaux hébergent de nombreuses maladies et habitent fréquemment les zones urbaines.

Mots clés : urbanisation, corbeau américain, flexibilité écologique, habitat

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Introduction

Spatial variation in species abundance is often influenced by landscape characteristics (Siriwardena et al. 2012). These characteristics include, but are not limited to, habitat homogeneity, satisfaction of niche requirements, and abiotic requirements (Frutos et al. 2016; Brown et al. 1995; Boulangeat et al. 2012). For some species, spatial variation in abundance concurs with the abundant-centre hypothesis, where species are more abundant at the centre of their geographic range (Brown 1984; Shalom et al. 2020). For most, however, the ecological niche model is observed instead: species abundance declines with greater distance from areas satisfying local niche requirements (Martínez-Meyer et al. 2013). In both cases, landscape characteristics play an important role in dictating abundance.

Urbanisation drastically changes the landscape. This can be due to direct changes, such as habitat loss and habitat fragmentation (Ortega-Álvarez & MacGregor-Fors 2011; Liu et al. 2016; Scolozzi & Geneletti 2012), or indirect changes, such as changes in native vegetation characteristics (e.g., abundance of native plant species, vegetation cover; Pennington et al. 2010) Thus, many species are often limited to natural habitat fragments and consequently are more abundant in such as urbanisation exerts a filter effect (Lloyd 2008; Fischer & Lindenmayer 2002). Generally, in urban areas, habitat loss is the most important driver for species extinction (Dri et al. 2021; Fahrig 1997). As a result, few species are able to successfully live synanthropically. Some species, however, are successful in anthropogenic areas. Many of these species, the American crow (*Corvus brachyrhynchos*) for example, have a high degree of ecological flexibility which allows them to exploit anthropogenic habitats (Kövér et al. 2015; Daniels et al. 2019)

Ecologically flexible species are those that are better able to adapt to changes within their environment (Eppley et al 2017; Camin et al. 2016; Sol & Lefebvre 2003). Species with ecological flexibility often have a high dispersal ability, behavioural flexibility, and dietary flexibility (Daniels et al. 2019; Knaebe et al. 2017; Schratzberger et al. 2019). This flexibility allows species to colonise more habitats, especially urban ones, compared to non-flexible species (Kövér et al. 2015; Sol & Lefebvre 2003; Sol et al. 2002). This is because flexible species have broader niches and a better ability to exploit overlooked resources (van Toor et al. 2017; Tuomanien & Candolin 2010). Given this, urban land cover may be a good predictor for ecologically flexible species abundance as these species often respond differently to landscape and are able to occupy habitats otherwise unfit for non-flexible species. Where non-flexible species abundance is often correlated with size and quality of natural habitat (Lloyd 2008; Kajzer et al. 2011; Thornton et al. 2011), we could expect the opposite for flexible species, occupying more urban landscapes where there is a greater quantity of resources and less interspecific competition (Clucas & Marzluff 2012; Teglhøj 2017). Studies on landscape influence on species abundances have been completed on many species, but few have assessed the extent to which landscape affects the abundance of these ecologically flexible species.

Given the above, I wish to examine the extent to which landscape composition affects the abundance of ecologically flexible species, focusing on the American crow (*C. brachyrhynchos*). Though crows are subjected to the consequences of urban habitats, such as nutritional deficits for nestlings and human threats (Heiss et al. 2009; Bjerke & Østdahl 2004), they are still frequently observed in anthropogenic areas. For many species, urban areas are ecological traps as they present novel resources but decrease species fitness, ultimately resulting in a "sink", where mortality exceeds natality (Gilroy & Sutherland 2007; Delibes et al. 2008). Crows, however, such as the Hooded crow (*C. corone cornix* L.) and the Carrion crow (*C. corone*), have demonstrated population growth within urban habitats (Köver et al. 2015; Preininger et al. 2019). I hypothesise that abundance depends on landscape composition for ecologically flexible species, but that, contrary to ecologically inflexible species, ecologically flexible species respond positively to urban areas. I predict that *C. brachyrhynchos* will be more abundant in urban habitats for several reasons: (1) Urban habitats have less interspecific competition for resources and nesting habitats (Teglhøj 2017; Møller & Díaz 2018), (2) crows are highly capable of exploiting anthropogenic resources (Preininger et al. 2019; Marzluff & Withey 2009), (3) resources are more accessible in urban landscapes (Clucas & Marzluff 2012; Jerzak 2001), and (4) compared to rural habitats, animals in urban habitats show a greater tolerance towards humans (Samia et al. 2015; Clucas & Marzluff 2012). Additionally, crows have shown impressive cognitive abilities from self-control (Miller et al., 2019) to lasting human recognition (Marzluff et al. 2010). This intellect further allows crows to evade common (human) threats in urban habitats (Marzluff et al. 2010). I therefore expect that crows will be more abundant in more urban landscapes where there are more urban characteristics, such as residential and community infrastructure.

Whether or not landscape composition is significant for ecologically flexible birds can be useful to urban developers and public health officials. For one, this information allows us to predict changes of crow abundance following landscape modification. This is particularly important considering that crows are a key host species for many viruses, notably West Nile virus (WNv; Salmon et al. 1986; Montecino-Latorre & Barker 2018). With increased urban development, a greater mortality of crows due to WNv infection is expected (LaDeau et al. 2011). Consequently, transmission of the virus to humans via vector species, particularly mosquitoes, is also expected to increase (Ciota & Kramer 2013). Encephalitis and gastroenteritis infections are also of concern. Encephalitis can develop from WNv contraction (Lanciotti et al. 1999), and a high prevalence of crows carry *Campylobacter jejuni* – a bacteria that is the leading cause of gastroenteritis (Taff et al. 2016). Understanding how synanthropic and ecologically flexible species react to landscape modification can better prepare cities for incoming wildlife, thereby allowing appropriate strategies to be implemented to maintain the integrity of both human and animal health.

Methodology

Field sites

I selected 32 sampling sites representing a gradient of urbanisation in the City of Ottawa, Ontario, Canada. I used land covers from the Ontario Land Cover compilation (OLCC) v.2.0 layer in ArcGIS10.7.1 (ESRI, 2019 https://www.esri.com). The original OLCC file contained 29 land cover classes, but I condensed them into the following five classes: agriculture, grassland, forest, wetland, open water, and anthropogenic (Table 1). The anthropogenic class consisted of roads, pervious and impervious built areas, and infrastructure (e.g., residential houses, recreation centres, commercial buildings; OLCC Data Specifications Version 2.0, 2014). Each sampling site measured 1 km^2 and their landscape composition was determined by the percentage of cover for each of the five classes. I selected sampling sites at least 2.5 km apart, exceeding the mean adult crow home range (Yaremych et al. 2004), to minimise the likelihood of sampling the same birds in different sites.

Field surveys

I conducted visual surveys of American Crows from 19 April to 26 August 2021. Conventional point-transect sampling methods tend to have an overestimation bias (Buckland et al. 2006). Thus, I adopted the snapshot method for my visual surveys as it is the most effective point-transect method (Buckland 2006; Buckland et al. 2008). For each visit, I randomly chose five observation points by placing points within the sampling site using the point-map feature in ArcGIS. I selected my observations points within at least 125 m of the site perimeter, ensuring I observed crows well within my site boundaries. I visited my sites at least 1-2 hours after sunrise, when crows were no longer departing from their communal night roosts (Withey & Marzluff 2009). I visited each site seven times, changing the location of my observation points with each visit so that I assessed the entire site over the study period. Since bird activity varies throughout the day, detectability also changes (Palmeirim & Rabaça 1994; Robbins 1981; Rollfinke & Yahner 1990). I therefore restricted my observations to a 10-hour window, conducting my visual surveys between 8:00 and 18:00. To compensate for a potential time-of-day effect and to reduce temporal bias, each site was visited three times in the morning (8:00-10:59), twice midday (11:00-13:59), and twice in late afternoon (14:00-18:00).

I did not limit my observations based on weather. Weather can influence species distribution, activity, and detectability, and for species of higher trophic level, their distribution may follow that of their prey (Oedekoven et al. 2017; Robinson et al. 2017; Planillo et al. 2020). I obtained weather data from the Ottawa CDA RCS and INTL A weather stations' hourly data reports (https://climate.weather.gc.ca/). I used temperature (°C), wind speed (km/h), and precipitation (mm) during my surveying as control variables.

Statistical analyses

Although many authors use the Poisson regression to study species abundance due to zero-inflated data (e.g., Purcell et al. 2005, Zuria & Gates, 2013, Pickett & Siriwardena 2011), I used a Gaussian distribution for my general linear models. I chose this distribution because it was better supported (AIC Gaussian = 246; AIC Poisson = 392) and my data were not significantly different from a normal distribution (Shapiro-Wilk test, W = 0.95, p = 0.11). Since my multiple visits to each site were not independent of each other, I incorporated Site ID as a random variable. I used general linear models to estimate the relationship between the average number of crows at each site and the percentage of the five land cover types. Given my modest sample size (N = 32 sites), I first ran univariate models for each landscape type. From these univariate models, I selected only the landscape variables for which the p-value was less than 0.3 (Table 2). It is important to note that landscape covers often are not independent of each other and may be correlated (e.g., Mao et al. 2018; Burgin & al. 2016). Thus, I excluded any landscape variables that showed a high degree of multicollinearity, that is, variance inflation factors (VIF) greater than 5. For survey conditions, I standardised my control variables prior to analysis. I conducted all my statistical analyses in R version 3.6.0 (R Core Team 2019).

Results

I observed crows in all but one study site (31/32 sites; Figure 1). The total number of crows observed ranged from 1 to 39 (mean ± se = 15.53 ± 1.92). Predictor variable candidates for my final model to explain this variation in abundance included anthropogenic, grassland, and wetland cover (Table 2). My predictor variable candidates were significantly correlated (Figure 2). Urban cover was associated with less grassland (r = -0.40) and less wetland cover (r = -0.51).

Grasslands were positively associated with wetlands ($r = 0.35$). Unsurprisingly, given the modest correlations between my predictor variables, the VIFs were less than 5 and indicated that multicollinearity was not of great concern. I therefore included urban, wetland, and grassland land cover in my final model (Table 3).

Crow abundance did not vary with proportion of urban land cover in the sampling site ($r = 0.00$; $p = 0.93$; Figure 3A). I observed fewer crows when sampling sites contained more wetlands ($r = -0.03$) and grasslands ($r = - 0.03$; Figure 3BC). These relationships, however, were non-significant ($p = 0.28$ and $p = 0.66$ for wetland and grassland respectively). My final model (Table 3) explained little of the spatial variation in American crow abundance across Ottawa, Ontario, Canada (marginal $R^2 = 0.07$).

Regarding survey conditions, there were fewer crows as the day progressed ($r = -0.50$, $p = 0.002$). Indeed, a follow-up ANOVA revealed that there were more crows in the morning (mean = 2.91 ± 0.32 individuals; Kruskal-Wallis $\chi^2 = 9.26$, $p < 0.01$). Though, there was no difference in the number of crows observed between midday and afternoon (mean = 1.77 ± 0.34 and 1.66 ± 0.20 respectively). I observed fewer crows when it was warm ($r = -0.13$, $p = 0.43$) and windy ($r = -0.10$, $p = 0.57$). When there was greater precipitation, however, I observed more crows ($r = 0.01$, $p = 0.97$). The effects of climatic conditions on the number of crows I observed were all non-significant (Table 4).

Discussion

Landscape composition

Landscape composition did not predict American crow abundance. Though these results are contrary to my predictions that crow abundance would increase with more urban land cover, some previous studies have observed similar results, that is, no significant effect of anthropogenic land cover on the abundance of crows at the local scale (e.g., Marzluff & Withey 2009; Haas et al. 2020). There are other factors, however, that may explain why my predictions were not supported.

The relationship between landscape composition and species abundance may not be linear (Batáry et al. 2017, Callaghan et al. 2019). Rather, abundance can peak at intermediate levels of urbanisation and higher landscape composition heterogeneity (Batáry et al. 2017; Vigallon & Marzluff 2005). Each landscape type may have its own resources, thus a heterogenous composition may maximise the quantity and/or diversity of exploitable resources (Batáry et al. 2017). So, rather than seeing peak abundance when one landscape type dominates like I had previously predicted, we could observe a more curvilinear relationship where species abundance peaks when there is a greater diversity of land cover types. Indeed, a curvilinear relationship has previously been observed with birds where abundance was highest in suburban areas (Batáry et al. 2017). Additionally, curvilinear models have supported variation in species abundance as a response to habitat characteristics where linear models could not detect significant effects (Meents et al. 1983).

Further, other factors may drive spatial variation in abundance. For one, it may not necessarily be the landscape type but rather the features present within that landscape that are important. For example, waste disposal sites and campgrounds have a high quantity of anthropogenic food sources, and aggregation of crows at sites with these features have been observed (Preininger et al. 2019; Marzluff & Neatherlin 2006; Wilson et al. 2015). Spatial variation in one landscape type has been observed not only with species abundance but also with mortality (Hager et al. 2013). There may therefore be spatial variation within a specific landscape depending on how humans are using the land and what features may consequently be present (Himsworth et al. 2014). Additionally, crows are highly social creatures that learn both from their peers (horizontal learning) and from their parents (vertical learning; Cornell et al 2012). Indeed, many ecologically flexible species that exploit anthropogenic resources have a high degree of sociality as this allows for higher learning and better navigation in complex environments (Kark et al. 2007). This sociality and high learning ability allows crows to avoid high-risk areas – that is, areas associated with threatening people or predators, or where conspecific death has occurred (Cornell et al. 2012; Swift & Marzluff 2015). Though there tends to be differences in human attitudes towards wildlife across different landscape types (Bjerke & Østdahl 2004), crows still avoid who or where they perceive to be dangerous (Clucas et al. 2013; Cornell et al. 2012). Thus, depending on past interactions between crows and my sampling sites, it is possible that some of my sites were intentionally avoided if these areas were associated as dangerous. Consequently, the land cover types present in those sampling sites would not sufficiently predict variation in abundance.

Additionally, the scale at which a study is conducted is important. We may not see an effect of landscape composition on ecologically flexible species at the local scale, but perhaps at larger scales (Marzluff & Withey 2009; Batáry et al. 2017; Benmazouz et al. 2021). Indeed, this has been observed with crows as well as other members of the Corvidae family (Marzluff & Withey 2009; Benmazouz et al. 2021). A multi-scale analysis would thus be useful in highlighting factors that may influence the distribution of species with flexible foraging strategies and habitat requirements (Haythornthwaite & Dickman 2006). Though there may be general population trends at larger scales, landscape context and history should be considered. That is, structurally similar areas may yield differences in species abundance simply because of the area's history and specific characteristics (e.g., habitat age, habitat management by humans, etc.; Basile et al. 2021).

American crow detection

Surveying conditions, with the exception of time of day, did not influence the number of crows observed. Many studies complete their visual surveys in the morning as, for many bird species, this is when there is peak activity (Robbins 1981). I, too, observed more crows in the morning compared to later hours. Despite previous studies observing an influence of rainfall on species abundance (Yoshida et al. 2021; Haythornthwaite & Dickman 2006), there was no relationship between precipitation and the number of crows I observed. This may be attributed to little variation in precipitation during my visual surveys – for most of my study, there was little to no precipitation when I was conducting my observations. Thus, it is unsurprising that there was no effect observed of rainfall on crow abundance. Though there was more variation in temperature and wind speed, I did not observe an effect of these factors on crow detection either.

Implications & Future Research

Though this study may provide insight into the effects, or lack of, of landscape composition on the abundance of ecologically flexible species, it is important to exert caution when generalising groups of species as predictors for abundance can be species-specific. For example, with gulls, another flexible group, their abundance may not only be influenced by landscape composition but also by biome type (freshwater, terrestrial, marine; van Toor et al. 2018). Additionally, closely related species in an urban habitat may still present differences in foraging strategies and habitat use (Lato et al. 2021).

It may be worth evaluating variation in abundance at different spatial scales. Though I did not observe an effect of landscape composition at the local scale, we may observe a higher abundance of crows in the City of Ottawa compared to surrounding municipalities with less urban cover. This is particularly important as Ottawa is not only one of the fastest growing Canadian cities but has previously been subject to WNv outbreaks (Statistics Canada 2022; Giordano et al. 2017). Thus, an increased influx of crows into the city risks increasing susceptibility to WNv as transmission between host species (e.g., crows) and humans is facilitated.

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Table 1. Categorization of land cover types from the Ontario Land Cover Compilation (OLCC Data Specifications Version 2.0, 2014) used in the prediction of American crow abundance in Ottawa, Ontario, Canada in summer 2021. Land covers that were not present in the study area were not included in the landscape analysis.

OLCC Unit Name	Description	Present in Study Area	Category
Clear Open Water	Water with no turbidity or sediment	Yes	Open Water
Marsh	Water table seasonally or permanently at or above substrate surface, tree or shrub cover < 25%	Yes	Wetland
Swamp	Water table seasonally or permanently at or above substrate surface, tree or shrub cover > 25%	Yes	
Fen	Water table seasonally or permanently at or above substrate surface, tree cover <25%, sedges, grasses and low (<2m) shrubs cover dominate	Yes	
Bog	Water table seasonally or permanently at or above substrate surface, tree cover ≤25%, sphagnum peat substrate	Yes	
Treed Upland	Tree cover >60% with >75% of the canopy being from upland tree species > 2m in height	Yes	Forest
Deciduous Treed	Largely continuous forest canopy (>60% cover) composed primarily of deciduous tree species	Yes	
Mixed Treed	Largely continuous forest canopy (> 60% cover) composed of both coniferous and deciduous species	Yes	
Coniferous Treed	Largely continuous forest canopy (>60% cover) primarily composed of coniferous species	Yes	
Plantations – Trees Cultivated	Tree cover > 60% with trees >2m in height, uniform tree type	Yes	
Hedge Rows	Tree cover > 60% with trees >2m in height, uniform tree type	Yes	
Alvar	Limestone with shallow substrate (<15cm) dominated by grass and sedge	Yes	Grassland
Community/Infrastructure	Clearings for human settlement and economic activity, such as residential areas, urban recreational areas, and roads	Yes	Anthropogenic
Agriculture and Undifferentiated Rural Land Use	Land that has been cleared for agricultural use, and agricultural features (e.g., forage crops, rural properties)	Yes	Agriculture

Turbid Water	Waterbody with turbidity and high concentration of suspended sediment	No	-
Shoreline	Mineral substrate with <25% vegetative cover	No	-
Mudflats	Unvegetated coastal area partly submerged depending on tidal cycle	No	-
Heath	Raised mineral soil deposits along coastlines	No	-
Sparse Treed	Treed area with a sparse canopy composed of coniferous and/or deciduous species >2m in height with	No	-
Disturbance	Disturbed areas (e.g., clearcut, burned) by natural and/or anthropogenic means	No	-
Open Cliff and Talus	Vertical or near-vertical exposed bedrock with <25% vegetative cover	No	-
Sand Barren and Dune	Exposed sands formed by shoreline or aeolian processes	No	-
Open Tallgrass Prairie	Ground layer dominated by graminoids, tree and shrub cover <25%	No	-
Tallgrass Savannah	Ground layer dominated by graminoids, 25% < tree cover < 35%	No	-
Tallgrass Woodland	Ground layer dominated by prairie graminoids, 35% < tree cover < 60%	No	-
Sand/Gravel/Mine Tailings/ Extraction	Exposed soils, namely beach deposits, quarries, mines, and mine tailings	No	-
Bedrock	Exposed bedrock with limited vegetation cover (<25%)	No	-

Table 2. Univariate models for landscape predictors of crow abundance in Ottawa, Ontario, Canada in summer 2021. Predictor variables with a p-value < 0.3 (*) were selected for further statistical analyses.

Variables	**t value**	**r**	**p value**
Agriculture	0.52	0.095	0.61
Anthropogenic	1.17	0.21	0.25*
Forest	-1.00	-0.18	0.32
Grassland	-1.22	-0.22	0.23*
Wetland	-1.68	-0.29	0.10*

Table 3. Final linear model investigating the relationship between landscape composition and American crow abundance. SE = standard error. Crows were observed at N = 32 sites in Ottawa, Ontario, Canada in summer 2021. Significant p values ($\alpha < 0.05$) are in bold.

Variable	**Estimate**	**SE**	**p value**
Intercept	2.46	0.89	**0.01**
Anthropogenic	0.00	0.01	0.74
Wetland	-0.03	0.03	0.28
Grassland	-0.03	0.07	0.66

Table 4. Effect of surveying conditions on American crow detection. SE = standard error. Crows were observed at N = 32 sites in Ottawa, Ontario, Canada in summer 2021. Significant p values ($\alpha < 0.05$) are in bold. Weather data were obtained from https://climate.weather.gc.ca/.

Variable	**Estimate**	**SE**	**p value**
Hour	-0.50	0.13	**0.002**
Wind Speed	-0.10	0.17	0.57
Precipitation	0.01	0.16	0.97
Temperature	-0.13	0.16	0.43

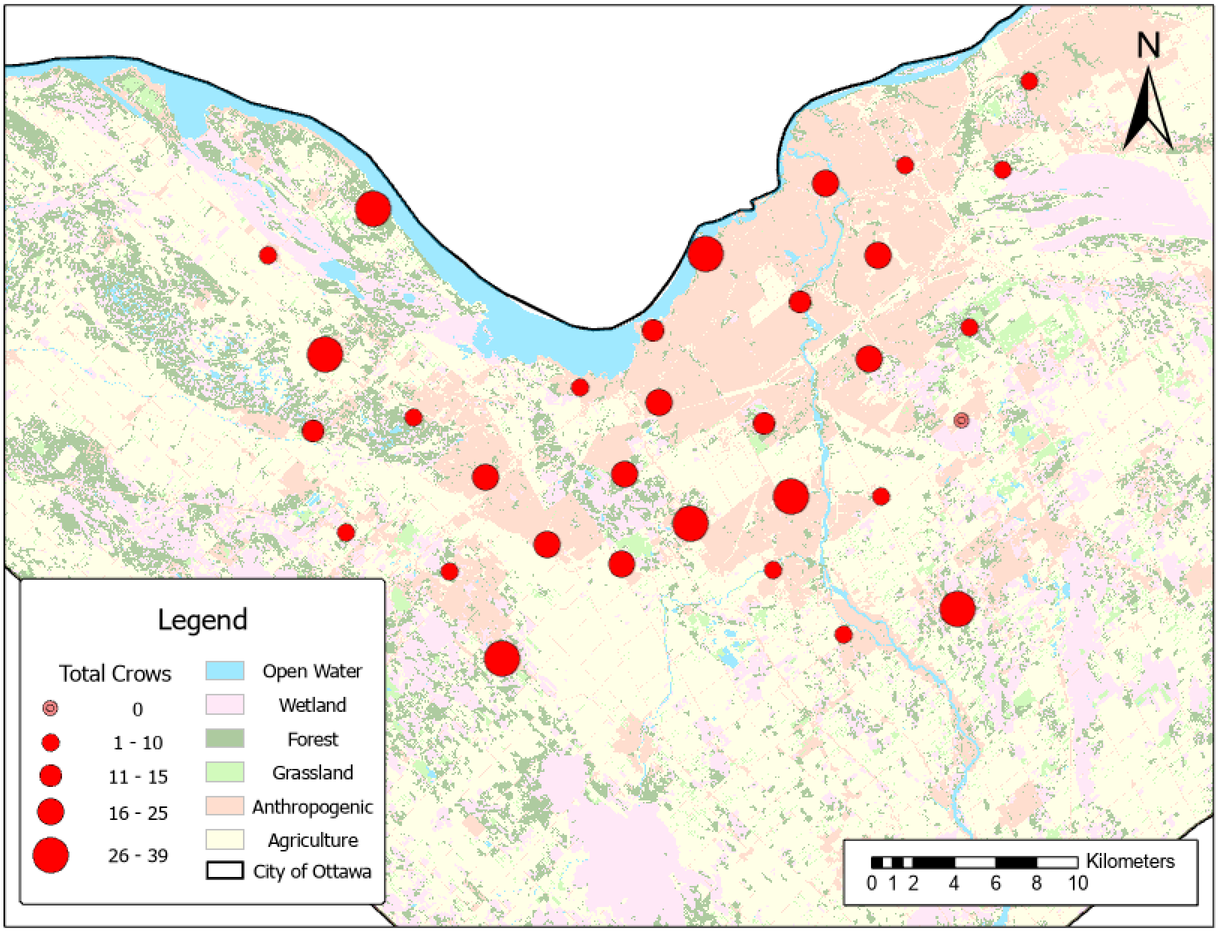

Figure 1. Total number of American crows observed at each site (N = 32) in Ottawa, Ontario, Canada, in summer 2021.

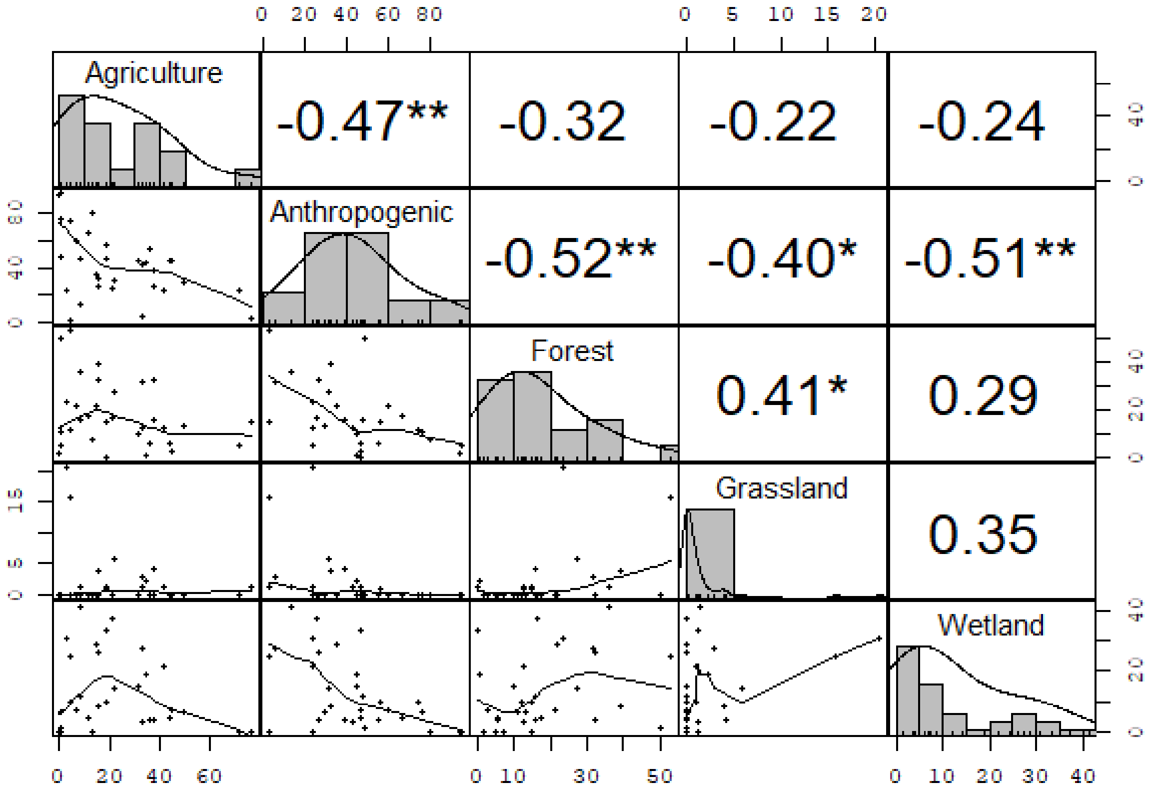

Figure 2. Correlations between American crow abundance in Ottawa, Ontario, Canada in summer 2021 and landscape composition. Frequency distributions are represented in the diagonal. Values in the upper portion represent Pearson correlation coefficients. * $p < 0.05$, ** $p < 0.01$.

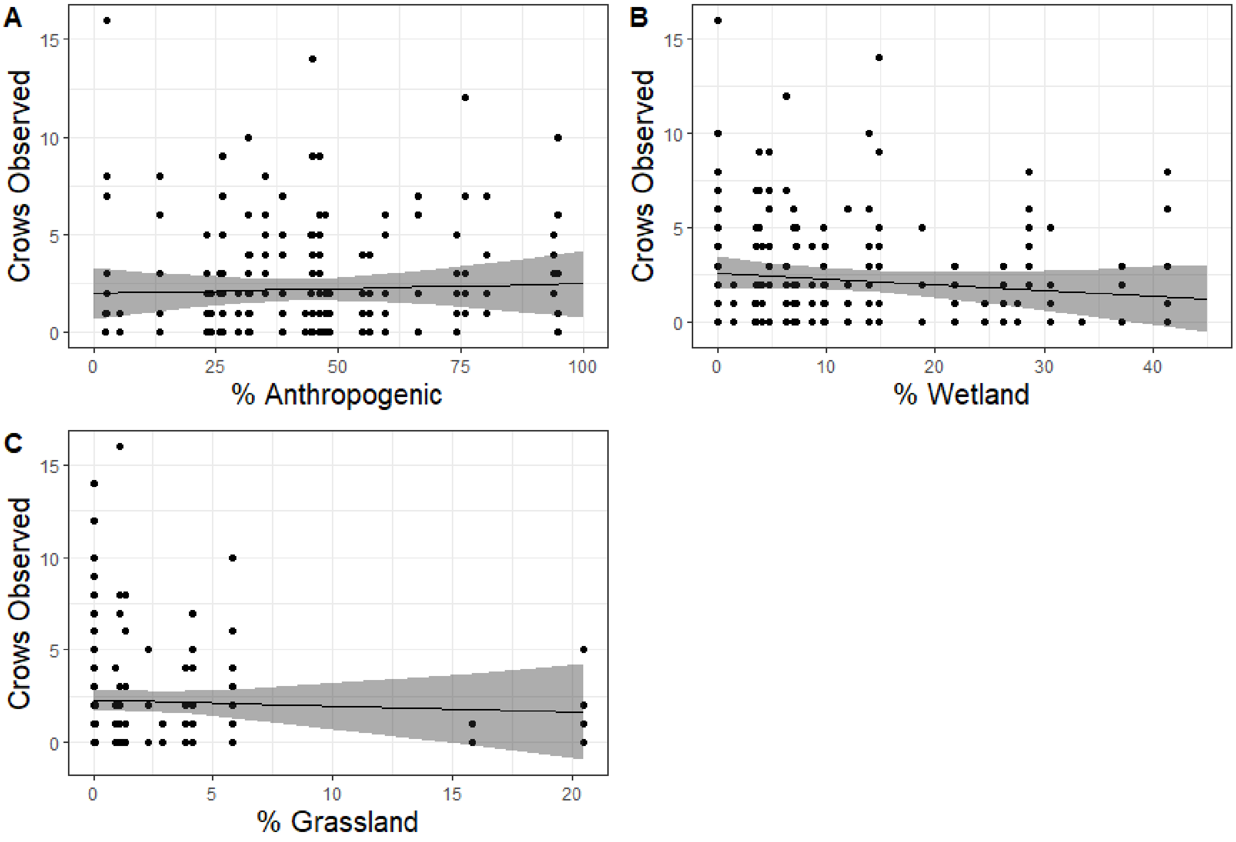

Figure 3. Crows observed in summer 2021 in Ottawa, Ontario, Canada as a function of the (A) urban landscape cover, (B) wetland cover, and (C) grassland. Points represent the maximum number of crows observed during one visit (n = 224 visits). Shaded areas represent the 95% confidence interval.