# Effects of anthropogenic activities on scavenger communities in freshwater riparian zones of eastern Ontario, Canada

**B. S. Etherington · M. L. Piczak · L. LaRochelle · A. J. Gallagher · S. J. Cooke**

**Abstract** Carrion as a food source and the role of scavengers both contribute to ecosystem connections, services, and food webs. Historically overlooked, there are paucities in the literature examining scavenging ecology and it remains unknown how anthropogenic activities such as riparian shoreline development impact scavengers. The objective of this study was to evaluate the effect of human disturbance on freshwater riparian zone scavenger communities and their activity. Using bluegill sunfish (*Lepomis macrochirus*) carcasses as carrion bait and trail cameras, we conducted a field experiment on Big Rideau Lake, Ontario, Canada, and contrasted developed (impact) and undeveloped (control) sites. We found that it took a similar amount of time for scavengers to locate and consume the carcass regardless of degree of development. Additionally, we determined that the composition of scavenger communities varied across impact and control sites, although this difference was not significant. Using generalized linear mixed modeling to investigate scavenging (binary), we found that the top models included total length of carcass, and distance to closest development, respectively. Further, there was a positive relationship between scavenging and both the distance to closest to development and the body size of bluegill sunfish (i.e., further distance to development and larger bluegill were more likely to be scavenged, respectively). Our results suggest that anthropogenic activities are likely imparting a negative effect on the scavenging community within freshwater riparian zones; however, the scavenging community may be able to offset the negative impacts through flexible feeding strategies.

**Keywords** Behavior · Ethology · Ecosystem functioning · Conservation · Carcass · Feeding behavior · Facultative scavenging

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## Introduction

Scavengers are organisms that consume carrion, which is a donor-dependent resource (Polis et al. 1997; Wilson and Wolkovich 2011; Kane et al. 2016). Obligate scavengers are rare and rely exclusively on carrion (Devault et al. 2003; Beasley et al. 2012), while facultative scavengers are more common and use carrion opportunistically as they are also predators (Devault et al. 2003; Wilson and Wolkovich 2011; Barton et al. 2013). There is a paucity of

studies investigating the role of scavengers in freshwater riparian zones, but it is generally understood that scavengers provide a range of important ecosystem services (Olson et al. 2012; Beasley et al. 2012; Moleón et al. 2014; Turner et al. 2017). For example, scavengers serve as biotic vectors that have the potential to recycle nutrients by moving them within the same ecosystem or translocating nutrients to adjacent ecosystems (e.g., from aquatic to terrestrial systems), thus providing critical nutrients in recipient habitats (Polis et al. 1997; Vanni 2002; Payne and Moore 2006; Beasley et al. 2012; Barton et al. 2013). Other ecosystem services provided by scavengers include the removal of carcasses from the environment (Inger et al. 2016b), thereby contributing hygienic benefits and reducing the spread of disease (Beasley et al. 2012).

Fish carcasses provide a readily available resource for organisms that live in or near water including freshwater riparian ecosystems. The mortality of fish can be caused by, but is not limited to pathogens, exposure to extreme environmental conditions (e.g., hypoxia, cold shock), senescence, injury (e.g., from a failed predation attempt), stress, starvation, or anthropogenically mediated fish kills, which result in the availability of fish carcasses to be scavenged (Ricker 1945; Schneider 1998; Nagrodski et al. 2012). Relative to their mass, fish sequester a large amount of micro- and macro-nutrients, such as phosphorus and lipids, and thus, fish carcasses are a nutrient and energy rich resource (Vanni 2002; Stevenson and Childers 2004; Boros et al. 2015). Fish carcasses are a food source for aquatic, semiaquatic, and terrestrial scavengers since they may remain in the waterbody or become washed onto the shore (Schneider 1998; Muhametsafina et al. 2014). For example, anadromous fish have been recognized as being a critical food resource for vertebrate scavengers (Polis et al. 1997). A wide variety of scavengers consume fish carcasses including reptiles, birds, aquatic invertebrates, and terrestrial vertebrates (Hewson 1995; Polis et al. 1997; Cederholm et al. 1999; DeVault and Krochmal 2002; Payne and Moore 2006).

The majority of scavenging studies have focused on undisturbed environments (Schneider 1998; DeVault et al. 2003, 2011; Turner et al. 2017). Yet, humans are a dominant force on Earth (Vitousek et al. 1997) to the point that it is now widely accepted that we are in the Anthropocene (Steffen et al. 2007).

Specifically, human activities directly impact over 50% of the Earth's terrestrial surface and have greatly altered the riparian zones of freshwater ecosystems (Strayer and Findlay 2010; Turner et al. 2017). Broadly, there is little known about the relationship between human activities and scavenger behavior (Beasley et al. 2015). Land use changes and habitat loss are two major anthropogenic factors that impact biodiversity, and while some species are more tolerant than others, the responses of species to land use change vary widely (Oliver and Morecroft 2014). Indeed, human impact (e.g., habitat alteration) has been found to be a driving factor in scavenger richness (Sebastián-González et al. 2019). Additionally, scavenger home range size and carrion removal rates are positively related (Gutiérrez-Cánovas et al. 2020); therefore, scavenging could be compromised in cases where home ranges are altered by anthropogenic activities. In general, it is well known that habitat quality can influence scavenger communities, scavenger abundance, and efficiency of carrion removal (Olson et al. 2012; Inger et al. 2016a; Turner et al. 2017; Schlichting 2019). Freshwater riparian habitas have been subject to intensive shoreline development (Wensink and Tiegs 2016; Cooke et al. 2022), with impacts on the scavenging community largely unknown.

Previous studies have suggested that future research should examine how anthropogenically caused land use change (often resulting in habitat loss) affects the function and efficiency of scavenging communities (Turner et al. 2017; Morales-Reyes et al. 2017). Further, the fate of carrion of freshwater habitats remains unknown (Beasley et al. 2012) and it is unclear how anthropogenic activities and development influence these processes. The objective of this study was to evaluate the effect of human development on riparian scavenger communities and their activity. Using bluegill sunfish (*Lepomis macrochirus*) as carrion bait, we investigated aspects of scavenging across developed and undeveloped sites (herein referred to as impact and control sites, respectively) within freshwater riparian zones. Specifically, we examined the degree to which impact and control sites influenced scavenging time and then differences across the scavenging community. Next, we examined drivers of scavenging including the degree of site development (i.e., impact and control sites), diel period (diurnal, crepuscular, and nocturnal), distance

to closest development, and bluegill body size. It is our hope that this research contributes to further understanding of the scavenging communities, which have been understudied in the past.

## Methods

### Study site and fish collection

Located in eastern Ontario, Canada, Big Rideau Lake is connected to two other lakes, collectively called the Rideau Lakes system (Fig. 1). Specifically, Big Rideau Lake (45.36 km²) is deep (max depth is 110 m) and oligo-mesotrophic. Big Rideau Lake has dense waterfront cottage development on some shorelines and is subject to heavy boat traffic. However, there are also areas of shoreline void of cottages and other human infrastructure that are in a more natural state.

Bluegill sunfish were angled (using Berkley Gulp Maggots bait, pink) from the northern portion of Big Rideau Lake (44.769931 N, − 76.214690 W; Fig. 1). Fish were kept if they were within the size range of 110–160 mm (Schneider 1998). The collected fish were then euthanized using cerebral percussion (CU-BIOL-Training Umbrella Protocol). Bluegill were collected and deployed the same day to control for level of decomposition and associated cues (e.g., odor).

### Site selection

All sites were located on the shoreline of the mainland such that island shorelines were excluded. Sites were scattered around the lake; however, the north shore was not used due to rapid and discontinuous changes in elevation (e.g., bluffs) that made riparian deployments impossible. There were two treatments: impact ($n = 18$) and control ($n = 15$; Fig. 1) for a total of 33 sites. A site was considered control if there was ~450 m of shoreline between the fish and any cottage (or other human infrastructure) on either side. For a site to be considered developed, it must be within 35 m of a cottage, human residence, or accommodation. The distance to the closest development or infrastructure to carcass deployment site was recorded. For impact sites, boathouses or docks
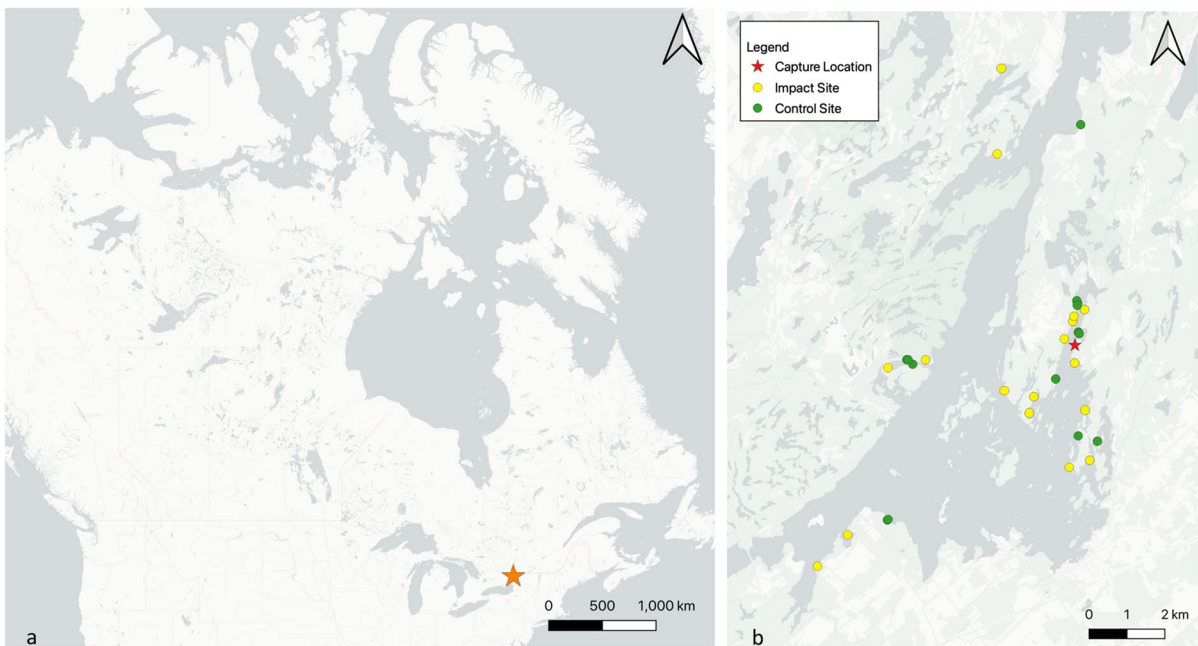


**Fig. 1 a** Big Rideau Lake (orange star), a part of the Rideau Chain of Lakes, is located in Eastern Ontario, Canada. **b** Bluegill sunfish were angled from the northern portion of Big Rideau Lake (red star), and field experiments for scavenging were conducted at impact sites (yellow circle; $n = 18$) and control sites (green circle; $n = 15$). (Color figure online)

may have been closer but they were not included to ensure a uniform definition across all sites (i.e., not all cottages have a boat house). In addition, permission of the landowner was considered during site selection, since bluegill were staked down on the shoreline. There was a minimum of ~450 m of shoreline between sites as to discourage the same individual scavenger scavenging other carcasses within close proximity. Also, a site may be revisited if sufficient time had passed to deploy another fish, but not in the exact same location (i.e., at least 10 m away from the previous location and separated by at least 7 days) so as not to train the animals to expect the bluegill carcasses.

Trial design

Trials began August 16, 2020, and continued through September 5, 2020 (which was the last collection of cameras). All camera setups were deployed between 1100 and 1500 h Eastern Time. Each day of deployment included an equal number of impact and control setups (Fig. 1). At each site, the bluegill was placed ~1 m from the edge of the water. The carcasses were staked down using a Y-shaped twig from the area surrounding the selected site. The twig was put through the gills and into the substrate to secure the carcass. This allowed for enough resistance for the trail camera (Stealth cam QV series) to a capture motion-activated video (set for 30 s) of the scavenger. During pilot studies, we attempted to gather data without staking the fish down, as this as is most natural scenario, but this resulted in the scavengers not being in the camera frame long enough to get a reliable visual identification to species. Once set up, we left the site and returned to collect the cameras at minimum 46 h after the time of deployment. We chose a window of 46 h for two main reasons: the first being to ensure equal time opportunities for diurnal and nocturnal scavengers to access the carcass, and secondly to give enough time for the carcass to be scavenged. Forty-four of the 50 (88%) camera deployments were successful, resulting in a total of 44 bluegill deployed across both impact and control sites. The six failed deployments arose because of the camera sensor did not trigger or the bluegill was out of the frame because it was washed away, or the camera shifted.

Data extraction

Upon collection, the videos were analyzed for the following information: if the fish was scavenged, the date and time, time of first detection, time until it was scavenged, and the species of the scavenger that consumed the carcass and/or removed the carcass from the camera frame. The time the fish was scavenged was further classified into three diel periods: diurnal (0700–1900 h), crepuscular (0500–0700 h and 1900–2100 h), and nocturnal (2100–0500 h). Various animals may have been detected in the video but in order for the carcass to be considered scavenged, the scavenger must have had mouth, paws, or beak on the carcass and be pulling on, eating pieces of, or removing the carcass from the stake and/or taking it out of frame.

Statistical analysis

A Mann–Whitney U two-tailed test was used to examine whether the treatment (i.e., impact and control sites) affected the time until scavenged. To compare compositions of scavenger communities across impact and control sites, we completed a Chi-square test. Next, to further investigate scavenging, we produced a binary dataset (i.e., scavenged = 1, unscavenged = 0), where each sample represented the scavenging status of an individual bluegill carcass at one site. A generalized linear mixed model (GLMM) was used to examine drivers of scavenging (binary response variable) including treatment (impact and control sites; categorical), diel period at detection time (diurnal, crepuscular, nocturnal; categorial), distance to closest development (m; continuous), and total length of bluegill (mm; continuous), with site (categorical) included as a random effect to account for repeated measures. We generated candidate models and used model selection to determine the final model structure with Akaike information criterion (AIC; Aikaike 1987). If AIC values were within 1.0 of the top models, they were also considered plausible models. Diagnostics were performed for model validation and included plotting the residuals (with a Q-Q plot for normality), residuals versus explanatory variables (for independence), and the residuals against fitted values (to verify homogeneity) to visually inspect model fit (Zuur et al. 2009). All procedures were conducted in R statistical environment using the

"ggplot2" (Wickham 2009) and "lmer4" (Bates et al. 2015) packages for data visualization and modeling, respectively. Although we accept a statistical significance of ($p < 0.05$), it has been recognized that the p-value alone does not measure the size of effect or importance of result (Wasserstein and Lazar 2016). We aim to examine the full strength of evidence (i.e., literature for context) in addition to the p-values, as to not reduce the analysis to the rigid "bright-line" rules (such as $p < 0.05$) during interpretation and when justifying conclusions (Wasserstein and Lazar 2016).

## Results

Within the 46 h time period, 32 of 44 (72.7%) bluegill carcasses deployed were scavenged. The fish deployed at impact sites ($n = 24$) had an average total length of $139 \pm 15$ mm and were on average $20.1 \pm 7.6$ m from development, with the closest being 3 m away and the furthest deployment being 31 m away. Fish deployed at control sites ($n = 20$) had an average total length of $137 \pm 11$ mm and were a minimum of 450 m linearly from development (minimum distance to development for control sites did not take into consideration the contour of the shoreline).

The percentage of fish scavenged across impact and control sites was 70% and 75%, respectively, with a similar time until scavenging was initiated ($p = 0.69$; Table 1). Bluegill carcasses at the impact sites were scavenged by raccoon (*Procyon lotor*), American mink (*Neovison vison*), common grackle (*Quiscalus quiscula*), and great blue heron (*Ardea herodias*; Fig. 2). Great blue heron was only observed scavenging fish in an impact site, while the deer mouse (*Peromyscus maniculatus*) was only observed scavenging in a control site (Table 2). At the control sites, bluegill carcasses were scavenged by raccoon, American mink, grackle, and deer mouse (Fig. 2).

**Table 1** The proportion and percentage of scavenged and the mean $\pm$ SD of the time surpassed between deployment and time scavenged in hours for both impact and control sites

| Site treatment | Fish scavenged (%) | Time until scavenged (hr) |
|---|---|---|
| Impact ($n = 24$) | 18 (75%) | $13.86 \pm 12.83$ |
| Control ($n = 20$) | 14 (70%) | $11.42 \pm 10.92$ |

Time until scavenged was similar across treatments ($p = 0.69$)

There were four additional species that detected the fish carcass: dog (*Canis familiaris*), garter snake (*Thamnophis sirtalis*), Northern watersnake (*Nerodia sipedon*), and muskrat (*Ondatra zibethicus*); however, they were not confirmed scavengers as they did not attempt to consume the carcass (Fig. 3). Additionally, we also detected sparrows (*Passer* spp.) at the deployment sites, but they did not directly interact with the fish carcass. We used American mink, raccoon, and grackle to represent the scavenger community (Table 2), as these three species were most prevalent and seen in both impact and control sites. Further, the Chi-square test revealed that the distribution of scavenger community varied across impact and control sites, although the difference was not significant ($X^2 = 4.89$, $p = 0.07$). Specifically, there were more American mink and grackle at impact sites, whereas there were more raccoons found at control sites (Table 2).

Through the GLMM, we determined that there were two top model candidates: total length, and distance, respectively (Table 3; Fig. 4). Further, scavenging was similar across impact and control sites, as well as throughout all diel periods: crepuscular, diurnal, and nocturnal (Fig. 4a, b; Table 3). There was a positive relationship between bluegill total length (mm) and scavenging, in that larger bluegill were more likely to scavenged (Fig. 4c; Table 3). There was also a positive relationship between distance, when developments were further away, the carcass was more likely to be scavenged (Fig. 4d; Table 3).

## Discussion

The purpose of this study was to gain a better understanding of scavenging ecology within freshwater riparian habitats, as well as to examine associated impacts of anthropogenic activities stemming from development. Using field experiments conducted on Big Rideau Lake, we found that a variety of taxa and species scavenged bluegill sunfish, with American mink scavenging most frequently. Additionally, it took a similar amount of time for scavengers to locate and consume the carcass across impact and control sites. We also found that the scavenger community varied across impact and control sites, although the difference was not significant. Through the GLMM, we determined that there were two

**Fig. 2** Images of scavengers **a** Raccoon (*Procyon lotor*) at an control site August 29, 2020, **b** American mink (*Neovison vison*) at an impact site August 29, 2020, **c** Common Grackle (*Quiscalus quiscula*) at a control site August 28, 2020, **d** Great blue heron (*Ardea herodias*) at an impact site August 18, 2020, and **e** Deer mouse (*Peromyscus maniculatus*) at a control site September 3, 2020

**Table 2** Proportion and grand total of each scavenger present for both impact and control sites at Big Rideau Lake

| Treatment | Scavenger | | | | | |
|---|---|---|---|---|---|---|
| | American mink | Raccoon | Grackle | Great blue heron | Deer mouse | Total |
| Impact | 14 | 1 | 2 | 1 | 0 | 24 |
| Control | 7 | 5 | 1 | 0 | 1 | 20 |
| Total | 21 | 6 | 3 | 1 | 1 | 44 |

The community composition varied across impact and control sites, although the difference was not significant ($X^2 = 4.89$, $p = 0.07$)

top models: fish total length, and distance, respectively. Specifically, there was a positive relationship between scavenging and both the distance to closest to development and the body size of bluegill sunfish (i.e., further distance to development and larger bluegill were more likely to be scavenged,
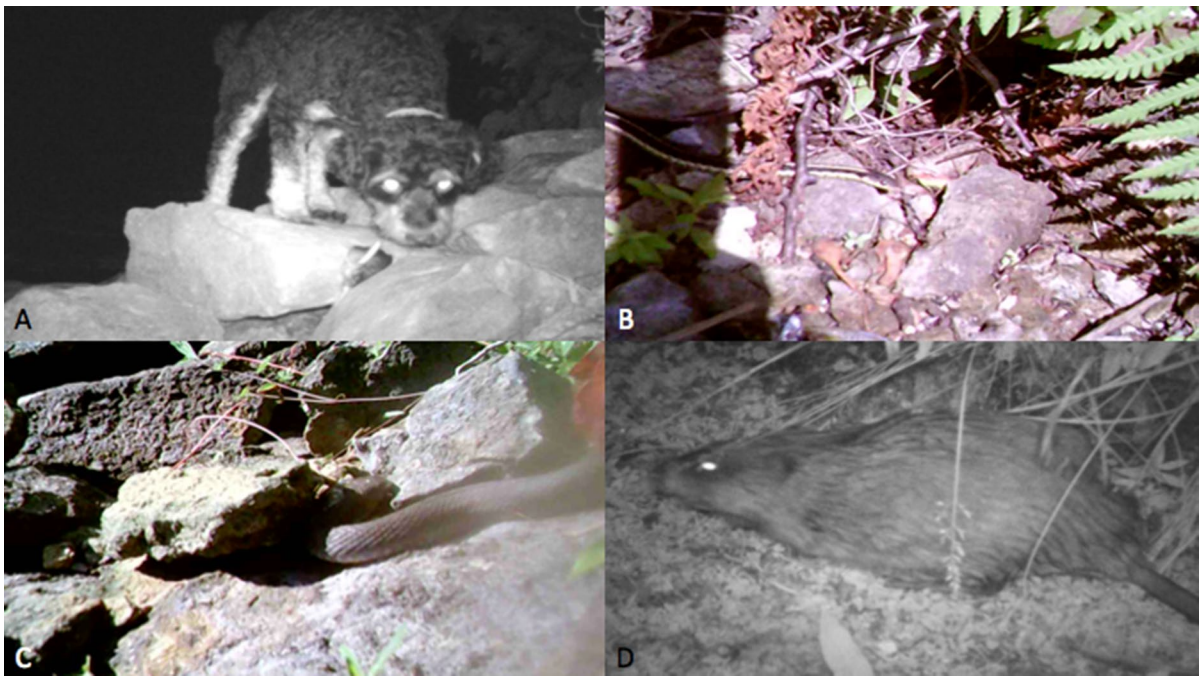
**Fig. 3** Images of animals detected with the bluegill carcass at impact sites **a** Domestic dog (*Canis familiaris*) on August 17, 2020, **b** Garter snake (*Thamnophis sirtalis*) on August 26, 2020, **c** Northern watersnake (*Nerodia sipedon*) on September 4, 2020, and **d** Muskrat (*Ondatra zibethicus*) on August 20, 2020

**Table 3** The influence of site development (impact or control sites; categorical), diel period (diurnal, crepuscular, or nocturnal; categorical), total length of bluegill sunfish (mm; continuous), and distance to closest development (m; continuous) on scavenging (binary response variable) as determined by a generalized linear mixed model

| Model terms | AIC | Log likelihood | Deviance | df |
|---|---|---|---|---|
| **Total length** | **47.9** | **− 21.0** | **41.9** | **39** |
| **Distance** | **48.9** | **− 21.5** | **42.9** | **39** |
| Site development | 49.6 | − 21.8 | 43.6 | 39 |
| Site development + Diel period + Total length + Distance | 50.5 | − 18.2 | 36.5 | 35 |
| Diel period | 51.3 | − 21.7 | 43.3 | 38 |

Site number was also included in all candidate models as a random effect (categorical). The top model is bolded

respectively). Further, we did find similar rates of scavenging regardless of site development or diel period. Our study confirms that there is an active scavenging community within freshwater riparian habitats in eastern Ontario, which likely contribute to ecosystem function as well as important ecosystem services.

We determined that bluegill carcasses were more likely to be scavenged in cases where the closest development was further away, suggesting that anthropogenic activities may be impacting scavenging opportunities. Indeed, it has been shown that scavenger assemblages in areas with high amounts of human activity supported fewer scavenger species with a lower richness (Sebastian-Gonzalez et al. 2019). Those findings were consistent with ours in that the scavenging community differed slightly (albeit not significant) across impact and control sites, also pointing to negative human impacts. Alterations to the scavenging community composition can result in indirect, cascading effects within the ecosystem. For example, where populations of vultures declined (*Gyps fulvus*), scavenging opportunities and efficiency of other scavengers including the ref fox (*Vulpus vulpus*) increased (Morales-Reyes et al. 2017). The functional dynamics of the scavenging community are susceptible to anthropogenic activities, and
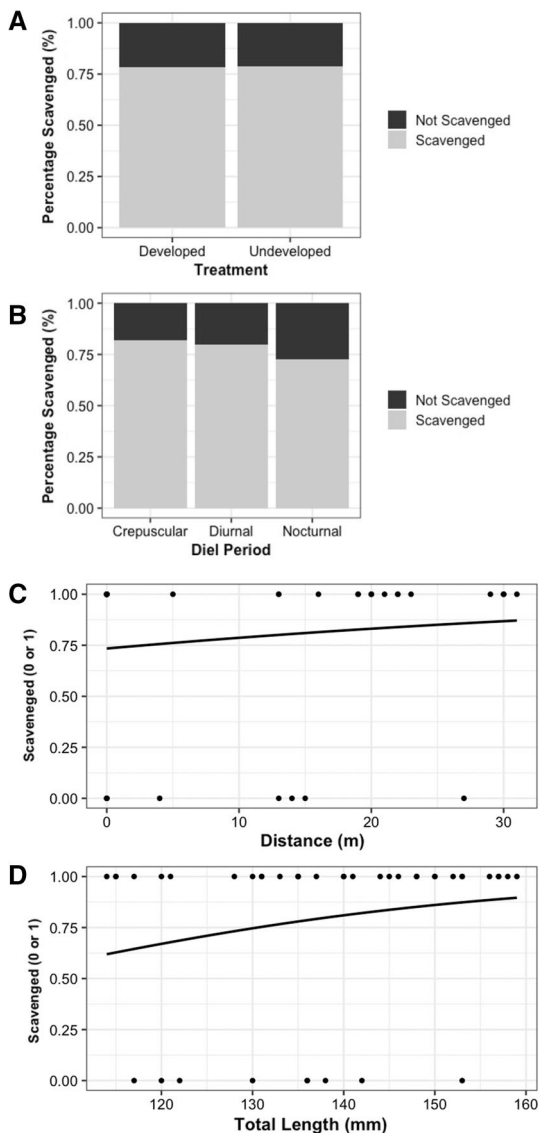
**Fig. 4** The influence of (**A**) treatment (impact, developed and control, undeveloped sites) and (**B**) diel period did not significantly impact scavenging of bluegill sunfish. (**C**) Total length (mm) of bluegill sunfish carcases was positively related to whether or not the carcasses were scavenged (0 = not scavenged and 1 = scavenged), where larger carcasses were more likely to be scavenged. There was a positive correlation between (**D**) distance (m) and whether or not the carcasses were scavenged

this is of concern because associated ecological services could be altered or jeopardized.

The scavengers identified within this study such as American mink, raccoons, and great blue herons are not surprising as many of these species have been

reported as scavengers in similar studies on simulated fish kills in temperate regions of North America (Ryon et al. 2000; Muhametsafina et al. 2014). In both impact and control sites, American mink were the most prevalent scavenger. American mink cover a large area with their home range being between 1 and 5 km$^2$ (Basu et al. 2007). With their resting sites usually being abandoned bank burrows of muskrats and roughly half their diets being composed of fish. American mink are commonly described as semiaquatic mustelids (Basu et al. 2007; Haan and Halbrook 2014), which can excavate buried carrion (DeVault et al. 2003). These traits of American mink are likely contributing to their success in scavenging fish carcasses observed in our study, as they may be more likely to arrive at the carcass before any other scavengers.

We found that there was a positive relationship between the size of the bluegill carcass and scavenging, where larger bluegill tended to be scavenged more frequently than smaller ones. This is consistent with the seminal optimal foraging theory, which predicts that animals will tend to maximize their foraging success by optimizing search strategies (Pyke 1984). In the scope of an ecosystem, our field experiment supplied food sporadically and unpredictably, and the scavengers still selected for high quality food, as indicated by bluegill size (i.e., higher caloric value). Further, the optimal foraging theory also states that flexibility in feeding permits animals to survive in suboptimal environments (e.g., anthropogenically altered), where food resources may be scarce or unpredictable (Pyke 1984). This notion would be consistent with our findings that the scavenger community was similar across impact and control sites, suggesting that these generalist species are indeed flexible when it comes to feeding. This flexible feeding strategy (also demonstrated in Morales-Reyes et al. 2017) would likely contribute to increased persistence in the face of anthropogenic activities; however, full impacts to the rest of the ecosystem remain unknown.

One of the services scavengers provide is that they act as nutrient vectors across ecosystems (Polis et al. 1997; Vanni 2002; Payne and Moore 2006; Barton et al. 2013; Beasley et al. 2015). In this study, all of the scavengers observed were of terrestrial origin, potentially due to the proximity of the fish placement to the shoreline, meaning that the nutrients in the fish

carcass were being transferred from the aquatic to terrestrial ecosystem. This is not always the case as previous studies have reported species of freshwater turtles as scavengers of fish carcasses (Ricker 1945; Schneider 1998; Muhametsafina et al. 2014). The absences of freshwater turtle species scavenging the bluegill carcasses may be reflective of our relatively small sample size. It may be of benefit to investigate nutrients remaining in the aquatic system relative to the amount being translocated through scavenging in freshwater riparian zones.

There were four additional species that investigated the fish carcasses including domestic dog, Northern watersnake, garter snake, and muskrat, and it is highly likely that they could have potentially been scavengers under different circumstances. For example, although the dog did not directly take the fish, it may have discouraged a subsequent scavenger from approaching as it was seen marking its territory. Snake species are known to scavenge, and there are reports of snakes searching for and consuming small fish (DeVault and Krochmal 2002; Smith et al. 2017). Thus, Northern watersnakes could have been scavengers if they did not have restrictions such as limited gape, meaning the carcass may have exceeded their maximum prey size or lengthy digestion times (King 2002; Smith et al. 2017). Muskrats were also observed investigating the carcass site presumably because they detected the fish carcass or the remnants of the fish carcass, but arrived after it had already been scavenged. Given that muskrats have been reported scavenging fish, it is possible that under different circumstances they would have been included in the scavenger community (Muhametsafina et al. 2014).

Research on terrestrial environments found that anthropogenic activities negatively impact scavenger community composition (Beasley et al. 2015; Inger et al. 2016a). Our study did not find a difference in the efficiency of scavenger communities in impact sites compared to control ones. However, this warrants further investigation given that the lake as a whole could be considered relatively developed. Future studies should consider contrasting different waterbodies with varying levels of development (ranging from pristine with negligible human development and activity to high levels of development and use) with lake as the experimental unit rather than sites as we did here. It is possible that relative to another pristine waterbody with no development, scavengers across both impact and control sites in our study behaved differently or the scavenger composition was different if the level of disturbance on Big Rideau "spilled" over to influence scavengers in what we termed control sites.

Although our results suggest that the scavenging community in freshwater riparian zones is active, certain limitations associated with design could be addressed in future research. As a proxy for human influence, sites were chosen as developed based on their proximity to cottages. Unfortunately, for the duration of the deployment there was no way to control or document the actual human presence in the area. To address this issue in future studies, the variability in human presence could be better documented through interaction with the property owners (e.g., perhaps it is not physical presence of infrastructure but the presence of humans using that infrastructure). An additional limitation is that the deployment of the cameras for 46 h may not have been a long enough time window as there were cases where the carcasses were scavenged outside of this time period. Future studies could expand the amount of time the carcass is available to scavengers, as scavenging events in this study were limited to those in a 46 h window after deployment and not all carcasses were scavenged by this time. Previous studies on scavengers extended the time the carcass was available to as long as 4 days (Schneider 1998; DeVault et al. 2003). Although there may be a variety of potential scavengers of fish carcasses as seen in previous studies (Hewson 1995; Polis et al. 1997; Schneider 1998; DeVault and Krochmal 2002; Payne and Moore 2006; Muhametsafina et al. 2014), we found a few key species scavenged the carcasses more frequently. It is highly likely that additional species could be a part of this scavenging community as species usage of carrion is closely connected to seasonal shifts in diet and availability of food items (DeVault et al. 2011; Turner et al. 2017). Further, within the riparian zones of Big Rideau Lake, dense vegetation could have hindered bird species from spotting the carcass. Therefore, scavenger communities within riparian zones could differ from more open areas, which should be investigated further. Finally, in some cases sparrows were seen at the deployment site and it appeared that they did not directly interact with the fish carcass, but it is possible that they may be eating insects that had been attracted

to that location by the carcass. Thus, although the sparrows were not directly scavenging the carcass, they may have benefited from its nutrients indirectly. The experimental setup used in this study could not be used to collect data on smaller species such as insects. However, to further understand the links associated with fish carcasses as a food source, future studies should be adapted to investigate all potential scavenger interactions, including those involving insects.

We investigated the impacts of anthropogenic activity with freshwater riparian habitats on scavengers, an ecological community that has historically been overlooked. We determined that indeed, there is an active scavenging community within freshwater riparian habitats. Further, the scavenger community composition varied across impact and control sites, but the difference was not significant. We found that larger carcasses were more likely to be scavenged, which could be reflective of the flexible feeding strategies of these generalist species. We also determined that bluegill carcasses that were further from the closest developments were more likely to be scavenged. Taken together, our results suggest that anthropogenetic activities are likely imparting a negative impact on the scavenging community within freshwater riparian zones, whereby important ecological services could be compromised. However, the scavenging community may be able to offset the negative impacts associated with anthropogenic activities through flexible feeding strategies. Future research should further investigate impacts associated with development on scavenging communities at varying levels of development to advance our understanding.

**Authors' contribution**   All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by BE, LL, and MP. The first draft of the manuscript was written by BE, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

**Data availability**   Data will be made available upon reasonable request.

## Declarations

**Conflict of interest**   The authors have no competing interests to disclose.

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