**Discussion**

Our study sought to investigate how the presence of a sentinel and the foraging environment (generalized as either green areas or commercial areas) affected the behavior of foraging American crows. We initially hypothesized that the presence of a sentinel would decrease the individual vigilance of crow foragers, and that green areas would likewise decrease individual vigilance due to reduced ambient noise and longer lines of sight. We did not find any significant effects of sentinel presence on the behaviour of foragers apart from increasing the duration of all behaviours. Moreso, neither the generalized environment, disturbance frequency, nor group size significantly affected the presence of a sentinel in the videos. This unexpected result suggests that sentinel crows may decide to perform sentinel behavior based more on their energetic reserves rather than any environmental factors we tested. We found that the generalized environment had a significant effect on forager behavior, with green areas leading to longer bouts of foraging behavior and more transitions from the vulnerable to the alert state. This suggests that crows may perceive green areas as less safe, possibly because they spend more time being vulnerable. Overall, the study's findings do not fully support the initial hypotheses and suggest that sentinel behavior and forager behavior in crows could be influenced by complex interactions between individual factors and forager’s perception of the safety of their environment.

The lack of significant effects of sentinel behavior on forager behavior does not support the hypothesis that sentinel behaviour is an altruistic behaviour that provides benefits primarily to other group-members. Our findings that sentinel crows do not significantly influence the behavior of foragers contrasts with the results of previous studies that found that the presence of a sentinel led to a decrease in alert behavior and an increase in foraging efficiency for the group. One possible explanation for this lack of effect could be that sentinel behavior is more selfish in nature, primarily benefiting the sentinel itself rather than the group. This would support Bedneckoff's state-dependent model, where individuals make decisions based on their own energetic needs and the benefits they receive. If the alternative to being a sentinel is foraging without one, an individual with sufficient energetic reserves could decide to perform sentinel duties as a safer option. In urban areas, where high-calorie food patches are bountiful, individuals could be forgoing foraging to act as sentinels for their own safety. These sentinels only come down when they are below a critical energetic threshold past which performing sentinel behaviour is unfavourable. Another interpretation could be that the benefits of sentinel behavior are not easily discernible at the group level. This could suggest that the benefits of sentinel behavior are more subtle or indirect, such as providing a greater sense of security that allows foragers to focus more on foraging without actively reducing their vigilance.

Sentinel behaviour therefore may not always function as a cooperative strategy to benefit the group as a whole. Instead, it may be more self-serving; sentinels primarily benefiting from the increased vigilance and predator detection, and foragers receiving indirect benefits from the sentinel. The behavior of foraging group members could be more influenced by their own immediate needs and priorities rather than by the presence of a sentinel. This does not mean that forager will not utilize sentinel coverage, but some individual may use the benefits provided more than others, depending on how great the need to forage is. The relationship between sentinels and foragers could then be more complex than it appears, reinforcing the importance of considering individual differences and motivations when studying group behavior.

We found that the generalized environment had significant effects on forager behavior, particularly in terms of the duration of bouts of foraging behavior and the number of transitions from the vulnerable to the alert state. In green areas, crows exhibited longer bouts of foraging behavior, indicating that they spent more time actively searching for and consuming food. Likewise, there was an increase in the number of transitions from the vulnerable state to the alert state in green areas. This suggests that crows in green areas were more vigilant and alert to potential threats, possibly due to the perceived higher predation risk compared to commercial areas.

Green areas such as parks offer longer lines of sight and less ambient noise but could have a potentially higher predation risk compared to commercial areas. Though commercial areas have a greater frequency of disturbance, these disturbances could be from sources American crows are more tolerant to. One of the adaptations of urbanized species is an increased tolerance for anthropogenic disturbances, which could include pedestrians but also vehicles. In contrast, there are fewer vehicles and pedestrians in green spaces but more pets and raptors which could trigger a greater reaction in foraging crows. Anecdotally, when raptors or unleashed dogs disturbed the foraging crows, they often flew away and abandoned the site, suggesting these disturbances are perceived as considerably more dangerous than vehicles or pedestrians.

The increased duration of foraging bouts in green areas could suggest that they spent more time actively searching for and consuming food. This could be due to the need to search through vegetation or grassy areas for food items, which may be more dispersed or require more time to locate. In contrast, commercial areas seemed to offer easier access to food via an increased presence of litter and scraps of highly caloric human foods. Such foods, especially when on concrete or other such impermeable surfaces are easier to locate and quicker to consume than foods found in green spaces. This was observed in crows foraging in commercial areas which exhibited shorter bouts of foraging behavior but a higher peck rate than in green spaces. This could play a part in American crows shifting their foraging preferences for anthropogenic foods.

The increased perception of risk in green spaces could be due to foragers could require more time to find and manipulate food, and disturbances, though possibly less frequent, could be of a more threatening nature in green spaces than in commercial areas. The benefits provided by having longer lines of sight and decreased ambient noise could also be benefitting urban predators such as broad-winged hawks and red-tailed hawks which can often be seen perched nearby green spaces.

Our findings highlight how versatile the foraging strategies of American crows in urban areas can be. By altering their foraging behaviour based on the challenges and opportunities present in their foraging environment, American crows demonstrate a behavioural adaptability that is likely crucial for their success in a great diversity of habitats, including urban cityscapes. This is further demonstrated by the significant interaction we found between sentinel behavior and the generalized environment. This interaction suggests that the effects of sentinel behavior on forager behavior are not uniform across different environments.

In green areas, the number of transitions from a vulnerable to alert state exhibited by foraging crows is higher than in commercial areas, yet the number of transitions performed increases in green areas and in the presence of a sentinel is considerably higher than in the absence of a sentinel. The duration of bouts of alert behaviour are unchanged by the generalized environment, yet in the absence of a sentinel there is a substantial increase in the duration of bouts of alert behaviour in green areas. Conversely, when in the presence of a sentinel the duration of bouts of alert behaviour was shorter in green areas than in commercial areas. The magnitude of the increase in the duration of bouts of foraging behaviour in green areas was also greater in the absence of a sentinel compared to in the presence of a sentinel. This could be explained by forager use of the indirect benefits of sentinel presence, potentially allowing them to tolerate greater risks while maintaining sufficient anti-predator vigilance. In the absence of a sentinel, a crow may elect to abandon the foraging site if conditions are too risky, while crows in the presence of a sentinel could choose to remain and forage, all the while maintaining sufficient individual vigilance in addition to sentinel coverage. When conditions are tolerable, foraging crows could be choosing an all-or-nothing approach to foraging when in the absence of a sentinel, explaining the sharp increase in the duration of bouts of both alert and foraging behavior in green areas and in the absence of a sentinel.

In addition to sentinel presence and generalized environment, we also assessed the effects of three main environmental factors that could affect forager behaviour, namely disturbance frequency, bait presence, and group size. Higher disturbance frequency led to a decrease in the duration of bouts of all behaviors, particularly foraging. This suggests that crows adjust their behavior in response to disturbances, possibly to minimize their exposure to perceived threats. However, the peck rate increased with disturbance frequency, indicating that crows may increase their foraging efficiency when disturbances are more frequent. One important caveat to keep in mind is that our measurement of disturbance frequency does not consider the type of disturbances. Areas with higher disturbance frequencies typically had a greater frequency of vehicular disturbances, which American crows may be more tolerant. As a result and following the risk allocation hypothesis, crows will continue to forage and may do so more intensely when doing so between cars. Higher disturbance frequency was also associated with a significant decrease in the number of transitions from foraging to alert behaviour, from which we can infer that crows will attempt to spend as little time as possible under threat while maximizing time spent foraging. Crows could then be foraging as quickly as possible and not taking the time to periodically look for threats (hence the decreased number of transitions), instead taking to the skies as soon as a threat is detected.

The presence of bait, which can be considered a proxy for human-generated litter in the environment, increased the peck rate and decreased the duration of foraging bouts. This suggests that foraging on bait or litter is more efficient and safer for crows, as it requires less time and effort compared to foraging on natural food sources. This observation could explain why a shift in preference for anthropogenic foods is observed in American crows and potentially other urbanized species.

As group size increased, the duration of bouts of foraging behaviour increased but was not associated with a decrease in duration of bouts of alert behaviour. The proportion of time allocated to either behaviour was also unchanged by the size of the group. This finding is surprising, as previous studies suggest that larger group sizes should decrease individual vigilance while increasing foraging efficiency, yet the effect of group size was only observed in the duration of bouts of foraging behaviour. Bouts of alert behaviour may have a minimal duration to effectively monitor the surrounding environment for sources of threat. Alternatively, foraging crows may be maintaining vigilance due to increased competition for resources in larger groups. Instead of only looking out for sources of threat, forager could instead be looking at the behaviour of other group-members in case they found a better patch to forage on.

Our study has several limitations that should be acknowledged. Our sample size may have limited the ability to detect significant effects. While efforts were made to collect a sufficient number of observations, we were limited by the crow’s decision to forage around the researcher. As such, caution should be exercised when interpreting the results, and further studies with larger sample sizes are required to make conclusive. Additionally, the study focused on the population of crows in inhabiting St. Catharines, which may limit the generalizability of the results to other populations or environments. Factors such as local food availability and predation pressure can vary widely between cities, and these factors may influence the behaviors observed in this study. Therefore, the findings of our study could differ from those of a similar study performed on a different population and in a different city. Our study also lacks a control group from a non-urban foraging site, the inclusion of which could demonstrate how urbanization as a whole can affect the social behaviour of crows. Although different urban areas were sampled in, the fact remains that only urban populations were observed, and less urbanized populations could behave in a different manner.

Furthermore, certain results from the study were difficult to interpret, particularly regarding the interaction between sentinel behavior and the generalized environment. The reasons behind these interactions are complex and may involve a combination of ecological, social, and individual factors that were not fully explored in this study. Future research should aim to further investigate these interactions to gain a better understanding of the underlying mechanisms.

Lastly, it is impossible to truly separate the effects of different factors from one-another. For example, the effects of generalized environment and disturbance frequency could be interrelated, as commercial areas will generally have increased disturbance frequency as a result of vehicular traffic, while green areas may have fewer disturbances but of a type that crows are less tolerant or intolerant to.

While our study provides valuable insights into the behaviors of crows in different environments, its limitations should be considered when interpreting the results, and further research is needed to fully elucidate social behaviour of urban crows. For example, future research could look at the levels and patterns of aggression in urbanized crows. This could provide further insights into how urban environments influence social behavior and could involve observing interactions between crows in different urban settings and comparing them to interactions in less urbanized areas.

Our study investigated the effects of sentinel behavior and the generalized environment on the behavior of foraging crows in urban environments. Contrary to expectations, sentinel behavior did not have a significant effect on forager behavior. This suggests that sentinel decision-making may be more influenced by individual needs rather than group benefits, aligning with Bednekoff's state-dependent model. The generalized environment had a significant impact on forager behavior. Crows in green areas exhibited longer bouts of foraging behavior and more transitions from the vulnerable to the alert state compared to those in commercial areas. This indicates that environmental factors such as resource distribution and predation risk play a crucial role in shaping forager behavior. Disturbance frequency, bait presence, and group size also influenced forager behavior. Higher disturbance frequency led to shorter bouts of behavior but increased peck rate, indicating a trade-off between vigilance and foraging efficiency. Bait presence increased peck rate and decreased foraging time, suggesting that foraging on anthropogenic food sources may be more effective for crows.

These findings have several implications for understanding crow behavior. They suggest that crows are able to adapt their behavior based on environmental conditions and individual needs. The lack of significant effects of sentinel behavior points towards the complexity of social behavior in crows and the importance of considering individual variation in decision-making. Overall, the study provides valuable insights into the factors influencing crow behavior in urban environments and highlights the need for further research to fully understand these complex behaviors.