**Introduction**

**Thesis summary**

Our objectives throughout this thesis were to investigate how sentinel behaviour could change in chapter 1, and then observe changes in behaviour in an urban sentinel species, the American crow, in chapter 2. The purpose of our research was to better understand how an environmental factor like urbanization could influence social behaviour. Sentinel behaviour, where individuals take watch over other group members, is an essential tool for the reduction of predation risk. The behaviour could be even more useful in human-altered environments where wildlife must navigate novel challenges and adapt to their surroundings. By observing changes in social behaviours and understanding the underlying mechanisms behind behavioural decisions, we could gain a better understanding of how these behaviours have evolved, and how they could continue to evolve in the future.

Our scoping review identified several intrinsic and extrinsic factors that can influence sentinel behaviour across several different species. Intrinsic factors such as sex, maturity, body mass, and satiation were found to affect the likelihood of performing sentinel behaviour. Males generally performed more sentinel behaviour than females, possibly due to differences in energetic investment between the sexes. Older and more experienced individuals also tended to sentinel more than younger individuals, likely because of their greater experience with threats making them more effective sentinels. Satiation and body mass were also found to influence sentinel behaviour, with heavier and more satiated individuals more likely to sentinel. The effects of intrinsic factors can be explained through the state-dependent model for sentinel behaviour, where the core motivators are the energetic reserves and the need for safety.

Extrinsic factors such as dominance, group size, and risk also played significant roles in shaping sentinel behaviour. Dominant individuals, usually males, were observed to sentinel more than subordinates, possibly due to their greater access to resources and additional benefits received from sentinel behaviour. Group size predictably influenced sentinel behaviour, with larger groups showing decreased individual sentinel behaviour but increased group-level sentinel behaviour. Increased risk, whether from predators, outgroup rivals, or the presence of pups, also led to increased sentinel behaviour. Overall, the review highlighted the complex interplay of intrinsic and extrinsic factors in shaping sentinel behaviour across species.

The factors identified in the scoping review generally aligned with the findings of chapter 2. There were no differences in the presence of a sentinel caused by generalized environment suggesting that environmental and energetic factors were equal throughout the different environments within an urban area. Additional studies on the behaviour of sentinel crows would be needed to verify that claim. The absence of effects of disturbance frequency and group size were surprising and could be due to differences in the types of disturbances, and increased availability of food in urban settings.

Our empirical study focused on investigating how the presence of a sentinel and the generalized environment affected the behaviour of foraging American crows. Unexpectedly, we found that sentinel presence had very few significant effects on forager behaviour, apart from significantly increasing the duration of all behaviours. This was contrary to our initial hypothesis, that the presence of a sentinel would decrease individual vigilance in foragers. It is possible that sentinel coverage had more subtle effects on foraging behaviours, potentially allowing group members to forage over a wider area without suffering an increased risk of predation. In contrast, the generalized environment had a significant effect on forager behaviour. Crows in green areas exhibited longer bouts of foraging behaviour and more transitions from the vulnerable to the alert state compared to those in commercial areas. This could be because green areas are perceived as less safe, possibly because they need to spend more time being vulnerable looking for food, or the presence of urban predators like the red-tailed hawk. The significant interactions between the effects of generalized environments and sentinel presence sheds light on how adaptable American crow behaviours can be and highlights their ability to succeed in urban environments.

The foraging environment could therefore influence sentinel behaviour in both the sentinel but also the response of foragers to the sentinel. Drawing from both the scoping review and the empirical study on American crows, we can infer the key effects of the generalized environment on sentinel behaviour. The availability and distribution of food resources can impact the need for sentinels. Litter, usually a highly concentrated patch of food, can be easier to locate and take less time to forage on than critters dwelling in tall grasses. Foraging in green spaces where vegetation obscures food, therefore, takes more time to find food, increasing the duration of time foragers spend vulnerable. This increased risk can result in individuals choosing to sentinel more often, though this was not observed in our study. Anthropogenic foods found throughout urban areas are also more calorically dense than more natural foods, potentially increasing the energetic reserves of individuals, and allowing urban individuals to sentinel more than their rural counterparts.

The frequency and types of disturbances could also alter the need to rely on sentinels. In commercial areas, foragers could encounter more vehicular disturbances than in green areas where the odds of encountering a raptor are higher. The latter disturbance could trigger a more urgent antipredator response than the former, to which crows could be much more tolerant towards despite the increased frequency of encounters. High-risk microenvironments in urban areas could lead to increased sentinel behaviour as individuals prioritize vigilance to reduce the risk of predation. In contrast, lower predation risk environments like commercial areas could result in a reduced need for sentinel behaviour as individuals feel safer and allocate more time to foraging.

Truly understanding the decision-making underpinning sentinel behaviour requires a holistic approach that considers a very wide range of individual and environmental factors. Determining how these factors interact and play a role in shaping the trade-offs associated with sentinel behaviour should be of particular interest to future studies. Furthermore, studying sentinel behaviour in urbanized species such as the American crow can provide unique insights into how animals perceive and respond to human-altered landscapes and can lead to a better understanding of how sentinel behaviour contributes to the success of these species.

**Limitations**

Despite the insights gained from our empirical study, we should acknowledge some of the limitations of the empirical study. One limitation is the relatively small sample size of crows observed, which may have limited the statistical power of our analyses. A larger sample size would have allowed a better examination of the factors influencing forager and sentinel behaviour. Collecting observations from a wider diversity of microenvironments could also help reveal more subtle environmental effects at play. Our study was conducted in St. Catharines, Ontario which is known for having a higher-than-average presence of green areas. This could limit the generalizability of our findings to other populations of crows in different cities with fewer green spaces. Factors such as local food availability, predator presence, and the distribution of green spaces can also vary widely between cities. Therefore, caution should be exercised when extrapolating our results to other populations or environments.

**Future Studies**

Future studies could improve on our findings by sampling over a greater breadth of urbanization, providing a larger sample size to increase the statistical power of their analyses. Additionally, researchers could consider conducting a long-term study to observe sentinel behaviour and forager responses over an extended period. This could allow the identification of temporal effects on the behaviour. Future studies could also sample populations from different cities to help improve the generalizability of our findings. The discovery of geographic differences in sentinel behaviour would be interesting and analysis of the causes of such differences could be fruitful in furthering our understanding of how social behaviours change in urban settings. A repeat study could look at the indirect effects of sentinel presence on foraging strategies could confirm the hypotheses proposed for the lack of effect of sentinel presence on forager behaviour. A more comprehensive evaluation of foraging environments, for example by measuring ambient noise during foraging events, could help reveal environmental factors we did not look at.

**Implications for Conservation and Urban Planning**

The findings of the scoping review and empirical study have several implications, particularly regarding the management of urban wildlife populations. By understanding the factors that influence social behaviours, conservationists and urban planners can develop more effective identify stressors in the environment and develop strategies to mitigate the negative impacts of urbanization on wildlife. Furthermore, an improvement in the knowledge of the effects of urbanization on social behaviour illuminates the mechanisms responsible for the evolution of the behaviour and how it could evolve in the future. Research on how social behaviours contribute to the success of species in urban environments could allow conservationists to improve conservation efforts by facilitating these behaviours in species at risk. Disrupting the social behaviours of urbanized species could lead to less harmful management techniques aimed at reducing their success.

**Conclusion**

The main findings from the scoping review and empirical study shed light on the factors influencing sentinel behaviour in urban environments, particularly in American crows. The scoping review identified a range of intrinsic and extrinsic factors that can affect sentinel behaviour, including group size, predation risk, and resource distribution. However, the empirical study found that sentinel presence did not have a significant effect on forager behaviour in American crows, suggesting that the effects of sentinel presence in urban areas can be more subtle than initially predicted.

The findings of this thesis can have several implications for understanding sentinel behaviour and its effect on forager behaviour. Our scoping review’s findings suggest that sentinel behaviour decision-making is complex and revolves around individual motivators such as energetic reserves and requirements for safety. The findings of our empirical study reinforce the importance of considering environmental factors affecting the behaviour of urban social species. While our study provides valuable insights, it also raises new questions and challenges that warrant further investigation and reemphasizes the need for further research to explore the effects of urbanization on the social behaviour of urban species, and its contribution to the success of these species.