***Chapter 1: Introduction***

1. *General Introduction of the Research Study*

Urbanization is the gradual shift of the human population towards cities. By extension, urbanization has the effect of changing the neighbouring environment around cities, and this has many negative effects that have caused a severe decrease in the world’s biodiversity. There are so many causes for this: habitat loss/fragmentation, increase in anthropogenic disturbances (noise, light, physical, etc) leading to stress, out-competition by invasive species and better adapted species. The latter species are synurbic, adapted to living in urban areas. As urbanisation increases, so does the abundance of these species. Why are these species to well adapted? There are many ways a species can adapt to urban areas: physiological, morphological, behavioral (**REFERENCE**). These behavioral adaptations are well documented at the individual level: changes in diet, increased intelligence, different nesting behavior, foraging behavior. These changes in behavior increase the fitness of the individual. Social species may have altered social behaviors to better take advantage of urban areas. Not much work has been done on this (show what, and if any work has been done on how social behaviors are affected by urbanisation. In other words: **Do social species gain an advantage from adapted social behaviors in urban areas?**

1. *Research Problem or Questions with Sub-Questions*

Introduction of the model species: Corvus brachyrhynchos. A social, synurbic species. There is evidence supporting this: as urbanisation increases, so have the numbers of crows in urban and suburban areas [1]. This is an excellent model species to test how adapted social behaviors can change, and benefit urban crows, potentially affecting their fitness in urban areas.

1. *Reasons or Needs for the Research Study*

The increase in corvid abundance could contribute to the negative effects urbanisation has on biodiversity. Urbanized species compete for the same resources as less adapted species, and this increased competition could be contributing to the loss of biodiversity. Moreover, this is a great opportunity to observe how plastic social behaviors can be, and how their effects are beneficial for a species.

1. *Definition and Explanation of Key Terminology*

The focal behavior of my thesis is **sentinel behavior**. Definition of sentinel behavior:  **An individual that adopts a prominent, exposed position to actively scan for predators or sources of threat while the other group members forage.** This has been documented in numerous mongoose, avian and even piscine species (Give references). In common crows, it involves an individual perching on a tree, building or power wire while group mates forage.

This behavior is largely understood to be one that directly affects the antipredator-foraging trade-off. This is a fundamental dilemma to life: the need to eat, and the need to not be eaten. When being a sentinel, an individual incurs a cost (lost-opportunity, energetic, etc) to benefit other group members (who pay a lesser cost: cost of being a social species since that is not a “free” behavior). In turn, these individuals can forage more effectively since they need to allocate as much effort to antipredator vigilance.

1. *Context of Research Study within the Greater Discipline (Area of Study)*

There is a huge debate around social behaviors and how/why it occurs. Some believe it is a case of direct reciprocity: you scratch my back (sentinel), I scratch yours (allopreening, social prestige, etc) **REFERENCE**. Others believe it is a case of inclusive fitness and kin-relatedness. I am participating in social behavior because it increases the odds of my genes being passed down by helping related individuals survive. Lastly, the controversial (multi-level) selection theory is another explanation for these supposed altruistic behaviors. It postulates that a group with more selfless individuals will perform better than a group with fewer selfless individuals (more selfish), even if individually, a selfless individual is less fit that a selfish one.

I believe that Bednekov’s state-dependent model best explains how individuals decide to perform sentinel behavior, and therefore the number of “altruists” in the group. Bednekov postulates that the decision to initiate sentinel behavior is based on selfish individual (energetic) state-dependent decisions.

Assumes the following:

* + Sentinel behavior is a low-cost activity performed by individuals that have sufficient energetic reserves from foraging.
  + The benefits of sentinel behavior arise only from an increase in personal safety, not from protecting other group members.
  + Safe refuges do not exist, therefore the sentinel’s post is the safest place to be if the alternative is foraging without a sentinel.

Considering urban areas provide more abundant sources of food, it would be logical that urban areas lead to increased sentinel behavior (**GIVE REFERENCES FOR urbanisation and body mass, body mass/energetic state for sentinel behavior).** This in turn should lead to increased foraging success for group members. This would explain how an increase or adapted sentinel behavior can lead to increased fitness in urban areas.

***Chapter 2: Hypothesis (Theory)***

1. *Brief Overview of Theoretical Foundations Utilized in the Study*

I will have two main chapters:

My scoping review

My empirical study

The objective of my scoping review is to determine what might affect sentinel behavior, a form of social behavior, to be adapted in urban areas. I had hypothesized that dominance rank, sex, and predation risk were the main deciding factors for the decision to invest energy into sentinel behavior. My predictions were that sentinel behavior would increase due to increased predation pressure (synurbic raptors give reference) and increased sources of stress caused by anthropogenic disturbances.

While dominance rank, sex, and predation risk do play an important part in sentinel behavior decision-making, another hypothesis better explains it: Bednekov’s model.

1. *Brief Overview of Literature Reviewed, Discussed and Applied*

Using the results of my scoping review, I will discuss the effects of each factor identified and give a detailed explanation to how and why each factor is important:

* + Sex and dominance usually go hand in hand, with more dominant individuals sentineling more than subordinates, and males sentineling more than females of the same rank. There is a frequent significant interaction between these factors
  + Predation risk increases the need for antipredator behavior, including sentinel behavior. In other words, a more stressful, unpredictable or dangerous environment should incite increased sentinel efforts.
  + Group size is relatively simple and will tie in very well with the body mass hypothesis: the greater the number of individuals, the more individuals can be sentinel. By that I mean that there will be more individuals capable, and energetically ready to perform sentinel behavior, causing a decrease in INDIVIDUAL sentinel efforts, but an increase in the GROUP’s sentinel efforts (less time without a sentinel in larger groups).
  + Body mass: the heavier an individual is, the more energy it has at its disposal. According to Bednekov’s model, there exists an energetic threshold past which an individual can become sentinel (dependent on assumptions). Tie this back into the other factors, apart from predation risk and include articles supporting this hypothesis. Explain that more dominant individuals tend to forage more effectively, and therefore spend less time on the group foraging. Give references to dominant individuals being first up.

In turn, the presence of a sentinel should benefit foragers by decreasing their individual need to be vigilant while foraging (**REFERENCE**). This would mean that individuals can forage more patches and do so more effectively. This will be the focus of my empirical study, where I observe the duration of behaviors of vigilance, foraging or movement, and the proportion of foraging time allocated to each behavior in the presence of a sentinel and in a green and commercial area.

Urbanized areas (here commercial) can have a huge effect on some of the factors mentioned. It is undeniable that sex and dominance rank will not act differently in both environments, but access to food and sources of stress increase. Urban areas are full of litter, garbage and whatever else a synurbic species might want to snack on and there is evidence to suspect that synurbic species actually prefer anthropogenic foods (availability, predictability, energetic content) even if these food sources are unhealthy in the longer term.

On the other hand, urban areas are also full of cars, humans, pets, unnatural sources of light and noise. On top of that, synurbic raptor species are present. All of which result in cities potentially being more dangerous than rural areas, though more profitable. As such I predict that sentinel behavior will increase.

If my prediction holds true, that individuals sentinel more in urban areas, then we should observe an increase in the time spent foraging and a decrease in the time spent vigilant in foragers. Because a sentinel is present and vigilant, the foragers do not need to be vigilant (head up). As a result, the increase in sentinel behavior can increase the foraging efficiency of group members in more urban settings, potentially contributing to the increased fitness these species have in cities.

1. *Study Model and Process Aligning with Literature Reviewed*

To test my hypothesis, I chose the American crow (*Corvus brachyrhynchos*) a social, synurbic species, and looked at their foraging behavior in green spaces and commercial areas of St. Catharines in Southern Ontario. American crows are a good model species because they have been identified as a synurbic species (**REFERENCE**) and are highly social. As such, they make a great model for testing adapted social behaviors in urban areas. Moreover, their increase in abundance could be problematic, since they compete with other, less urbanized, species potentially contributing to the loss of biodiversity caused by urbanization and the increase of urbanized species.

My methodology for testing is similar to other studies performed on foraging behaviors, with “head up” / “head down” being good indicators of the vigilance of foragers (Give references to articles using these behaviors).

1. *Hypotheses and Justifications Tied to Prior Sections or Statements*

I hypothesize that sentinel behavior affects the behaviors of foragers, and that these effects will be modified by the area in which the foragers are and the presence of a sentinel. In other words, that the foragers benefit from the presence of a sentinel, and that the group members will adapt their foraging behavior in response to both the presence of a sentinel and the type of environment they are currently in due to increased risk in commercial areas. Were I to measure the frequency of sentinel behavior in these environments, I would expect to find increased sentinel presence in commercial areas where anthropogenic disturbances cause increased stress in individuals (**REFERENCE**).

This ties into my scoping review where I determine what can affect sentinel decision-making and show that urban areas can cause an increase in the need for a sentinel. Therefore, sentinel should be more present in urban areas, where the benefits of this behavior are maximized. In turn, this adapted social behavior increases the fitness of urban crows, potentially contributing to their increase in abundance in urban areas. Their increase in abundance could, again, play a role in the decrease in biodiversity observed in and around cities, as crows compete for the same resources as other species.

1. *The Scope of Your Study with Theoretical Assumptions and Limitations*

My study seeks to determine how the behavior of foragers changes in response to the presence of a sentinel and determine how the environment in which the individual forages in affects the reliance of foragers on the sentinel. My study has certain limitations, however. I was not able to test whether or not sentinel behavior is more or less frequent in each area. Sentinels could be hidden from the camera or the observer during the data collection phase, and therefore it was uncertain if the individual apart from the foragers was a “true” sentinel or not. As such, we will use the" prominent, elevated position” definition of sentinel behavior, as opposed to any definition requiring a certain amount of time scanning. Another limitation I have is with foraging and caching behavior, where both behaviors involve an individual with their head down, but only one behavior is truly foraging.

The final objective of mine is to determine if this adapted social behavior plays a role in the increased fitness of synurbic species (crows) in cities.

***Chapter 3: Methods - SR***

1. *Introduction and General Description Study Method and Study Design*

Before starting my empirical study, I undertook a scoping review. The objective of the review was to determine **What can affect an individual’s decision to participate in sentinel behavior?** To see whether sentinel behavior could change in different environments. Sentinel behavior, as defined above, involves an individual apart from the rest of the group, exhibiting constant vigilance over the other group-members.

To perform this scoping review, I searched databases available to me, compiled the results, and screened articles using my pre-established inclusion and exclusion criteria. Following the title and abstract screening, I performed a full-text screening, taking notes in Obsidian. Later, I extracted data for a meta-analysis seeking to determine the effect size of the factors identified in the literature.

1. *In-Depth Description of the Study Design (Study Materials to Be Used)*

In order to minimize bias as much as possible, I wrote a proposal for the scoping review. This proposal included as much information as possible about the search, screening process, and data extraction. I did this to make sure my search was repeatable and as “fair” (see systematic) as possible.

I initially started by formulating my research question: **What can affect an individual’s decision to participate in sentinel behavior** and then developed a search string to use in different databases. The search string I found that captured the most relevant articles was **“Sentinel AND Behavio\*”** with some filtering performed in Web of Science.

I excluded review articles, and articles whose main concepts were unrelated to my study (e.g. Remote sensing).

After exporting and cleaning up the search results (**Enter number of studies**) I then performed an initial title and abstract screening using Metagear in R (**REFERENCE**) using a list of preestablished inclusion and exclusion criteria.

**Inclusion criteria**: Articles must test for the effect of a factor of interest on quantitative measures of sentinel behaviour (e.g frequency, duration, etc). Articles testing and observing the presence or coordination of sentinel behaviour in species will be kept in a separate group and used to determine how often coordination of sentinel behaviour is reported in the literature.

Bednekoff (2015) identifies coordination as the defining feature of sentinel behaviour, yet the general definition of sentinel behaviour for the purposes of this scoping review is:

“a form of animal behaviour in which one member of a group watches for potential predators while others in the group forage, rest, or engage in social interactions.” (APA Dictionary of Psychology, n.d.) I will add to this definition the requirement that the sentinel ocupy an elevated, exposed position.

Model species must be vertebrates.

**Reasons for Exclusion:** Articles must be from 1970 to 2021. Model species must not be aquatic, human or invertebrate. Articles must not be theoretical (mathematical) or reviews. Articles must not be about remote sensing.

After screening, I kept **XXX** articles for the full-text screening. I used Obsidian to gather notes and link together different articles by concepts I identified as potential factors included in sentinel decision-making. Of the **XXX** articles at the start **XXX** articles were rejected as I could not find a copy available to me.

Following my full-text screening, I had **XXX** articles left. These articles were used for the literary portion of my scoping review.

I then used Elicit (https:// elicit.org) to ensure I did not miss any articles in my initial search. The search queries I used are:

* + What can affect sentinel behavior?
  + How does [factor] affect sentinel behavior?

Where [factor] is a factor identified in my full-text screening. This includes

* + Sex
  + Dominance rank
  + Group size
  + Risk
  + Body mass
  + (energetic) state

The search results were screened using the same inclusion and exclusion criteria described above. **XXX** articles were added in this manner.

For the meta-analysis, I chose the proportion of time with a sentinel and the length of sentinel bouts as my focal measurements. I extracted data using JuicR in R (**REFERENCE**), and contacted the authors when data was not made available. **XXX** articles were included in the meta-analysis.

(**TENTATIVE**) I will use Hedge’s g as my measurement of effect size, and will calculate it in Metafor, a package in R. This package will also be used for subsequent analysis.

1. *Explanation of Sample to Be Used in the Study*

The measurements of sentinel behavior I decided to use in my meta-analysis are the proportion of time an individual was sentineling, and the duration of the bouts of sentinel behavior.

1. *Explanation of Measurements, Definitions, Indexes, etc. and Reliability and Validity of Study Method and Study Design*

As defined above, sentinel behavior consists of an individual exhibiting constant or near-constant vigilance over other group members from an elevated, prominent position.

The proportion of time an individual was sentineling will be calculated from the time an individual was sentineling, divided by the observation time.

The duration of bouts of sentinel behavior refers to the duration of each individual event of sentinel behavior an individual performs.

I will be using Hedge’s g as my measurement of sentinel behavior. It is derived from Cohen’s d, but is corrected for potential bias.

All of the methods of my scoping review will be found in the protocol for it.

1. *Description of Analytical Techniques to Be Applied and Justification for Them*

No idea yet.

1. *Reliability and Validity of Internal/External Design and Related Subtypes*

No idea yet.

1. *Assumptions of Study Method and Study Design with Implied Limitations*

I have made great efforts to minimize bias in my searches, screening, and analysis. To do so, I used a broad search string and reduced its scope by filtering by main concepts. During my screening process, I screened three times, and then made the final list. If there were conflicts in the screening decisions, I chose whether to include or exclude the study by looking at which decision had the majority among my three replicate screenings.

While I may have taken as many precautions as I could to limit bias, there exist still multiple potential sources of it. Many of these sources come from the fact that I did this alone and not with a team. Another may be the fact that I only searched Web of Science, but I complemented my results using Elicit to minimize loss of articles.

***Chapter 4: Findings - SR***

1. *Brief Overview of Material*

I identified a number of factors that could be contributing to sentinel decision-making, including sex, dominance rank, group size, risk and energetic state. The latter is the most interesting factor.

Bedneckov’s model suggests that sentinel decision-making is inherently selfish in nature, and depends on the energetic state or reserves of the individual. In other words, more effective foragers, or individuals with greater mass, tend to sentinel more, and for longer. This could explain differences in sentinel effort caused by apparent dominance rank and to a certain extent sex. More dominant individuals could be more capable foragers, or benefit from their position, and therefore can spend more energy and time into sentinel behavior. Moreover, males, who do not need to expend as much energy in offspring production, have more energetic reserves than females do, also explaining potential differences in sentinel effort.

That being said, the greater the number of individuals in the group, the more total “energy” it has, and therefore the individuals in the group can collectively sentinel less but gain greater sentinel coverage overall.

1. *Findings (Results) of the Method of Study and Any Unplanned or Unexpected Situations that Occurred*

**IN PROGRESS -**  However, it was unexpected to me to find that mass and energetic state are better explanations for this behavior, that I believed was altruistic or generated specific advantages to the group or individual. In other words, I did not expect to find that the best explanation for this behavior is a selfish one.

1. *Brief Descriptive Analysis*

**IN PROGRESS**

1. *Reliability and Validity of the Analysis*

**IN PROGRESS**

1. *Explanation of the Hypothesis and Precise and Exact Data (Do Not Give Your Opinion)*

I initially hypothesized that risk, sex and rank would be the main deciding factors involved in sentinel decision-making. However, I believe that Bedneckov’s State-dependent model for sentinel behavior is a better explanation.

**I DO NOT HAVE DATA YET**

***Chapter 5: Discussion - SR***

1. *Brief Overview of Material*

In my review (and meta-analysis), I’ve identified a number of factors that can alter the propensity of an individual to perform sentinel behavior. These include, but are not limited to sex, dominance rank, group size, and body mass. Interestingly, Bedneckov’s selfish, state-dependent model can explain the effects of sex and dominance on sentinel decision-making. Unfortunately, not many articles have tested for the effects of body mass, but a handful have tested for energetic state (satiation) which have found that sated individuals will sentinel more, and for longer bouts (**REFERENCE**). **Results from meta analysis will be important here.**

These factors can either increase or decrease an individual’s contribution to sentinel efforts. The combination of these factors can explain what we observe in nature.

1. *Full Discussion of Findings (Results) and Implications*

Sex is a binary trait that can greatly affect an individual’s sentinel effort. This can be explained through the lens of different energetic needs and allocations. Females expend incredible amounts of energy during reproduction: egg production and clutching consume a lot of energy, and the foraging opportunity losses from the latter behavior exacerbate this energy expenditure. As a result, when foraging, females will need to concentrate their efforts in replenishing their energetic reserves, and therefore may not be able to sentinel as early as males, nor for as long and as frequent (**REFERENCE**). Males therefore contribute more to sentinel behavior simply because they expend less energy during reproduction (the production of sperm is comparatively energetically inexpensive), with their energy being used more for territory, mate

1. *Full Discussion of Research Analysis of Findings*
2. *Full Discussion of Hypothesis and of Findings*
3. *Post Analysis and Implications of Hypothesis and of Findings*

***Chapter 6: Linking Statement***

***Chapter 7: Methods - Empirical***

1. *Introduction and General Description Study Method and Study Design*
2. *In-Depth Description of the Study Design (Study Materials to Be Used)*
3. *Explanation of Sample to Be Used in the Study*
4. *Explanation of Measurements, Definitions, Indexes, etc. and Reliability and Validity of Study Method and Study Design*
5. *Description of Analytical Techniques to Be Applied and Justification for Them*
6. *Reliability and Validity of Internal/External Design and Related Subtypes*
7. *Assumptions of Study Method and Study Design with Implied Limitations*

***Chapter 7: Findings - Empirical***

1. *Brief Overview of Material*
2. *Findings (Results) of the Method of Study and Any Unplanned or Unexpected Situations that Occurred*
3. *Brief Descriptive Analysis*
4. *Reliability and Validity of the Analysis*
5. *Explanation of the Hypothesis and Precise and Exact Data (Do Not Give Your Opinion)*

***Chapter 8: Discussion - Empirical***

1. *Brief Overview of Material*
2. *Full Discussion of Findings (Results) and Implications*
3. *Full Discussion of Research Analysis of Findings*
4. *Full Discussion of Hypothesis and of Findings*
5. *Post Analysis and Implications of Hypothesis and of Findings*

***Chapter 9: Conclusion***

1. *Summary of Academic Study*
2. *Reference to Literature Review*
3. *Implications of Academic Study*
4. *Limitations of the Theory or Method of Research*
5. *Recommendations or Suggestions of Future Academic Study*

* ***Chapter 10: References***