Results – Abridged

**Sentinel presence:** 25 vids, 13 obs in comm, 20 in green (small af sample size)

19 obs w/ sent 14 obs w/ no sent

G.Env did not affect sent pres

* makes sense since all still in urb env. So potentially higher energetic levels. Further research required across gradient of urbanization from natural to urban.
* Could be small sample size, making effect impossible to see. Needs more data

Group size did not affect sent pres

* Contrary to literature
* More inds in group = less ind contribution to sent BUT more overall sent
* Small sample size and gaps in the distribution of data (many at zero, some in the middle, few were high)

Dist freq did not affect sent pres

* Contrary to literature, risk did not increase the likelihood of a sentinel being present.
* Small sample size
* When dist too high, all group members left

Overall point to make: Cannot make any inferences about sentinel likelihood based on our results due to small sample size.

**Allocation of time to each behav:**

Similar proportion of time allocated to each behaviour

* Could be that the proportion of time remains largely fixed, and variations in the behaviours occur at the bout level (how often and for how long).
* Makes sense to remain constant since the needs remain relatively constant
* Would be interesting if these proportions change if comparing with “natural” populations outside of urban areas (less energy, more need for foraging)

No effect of sentinel presence

* Contrary to literature
* Sent. Pres should decrease prop time spent being alert.
* Decrease in alert behav or increase in foraging could be observed at the bout level

No effect of g.Env

* Could be that the env. Is perceived similarly, no extra threat associated with the env. Could also be that the proportion remains the same regardless of env, with variations occurring at a the bout level

**Duration of bouts**

Average duration of all bouts 1.75s

* Bouts of alert behav shorter than bouts of foraging
  + Less time required to be alert than to forage
  + More time required to manipulate and eat while foraging
  + Time required to look around much shorter

Sentinel presence increased the duration of all bouts, yet separately had no significant effect on either alert or foraging behaviour.

* Unsure why not significant when separate but significant together.

Generalized environment had a significant effect

* Longer bouts in green areas
* Could be driven by increase in duration of bouts of foraging behaviour
* Green areas perceived as safer?

Disturbance freq decreased duration of all bouts

* In line with literature
* Urgency! Could be a decrease in the duration of bouts of foraging as a result of needing to be alert more frequently

Interaction between sentinel presence and generalized environment

Discussion organization:

Subheadings to separate topics

First paragraph should be main points of interest (big findings, if present)

Have a separate section for “limitations” where you can put all the (repeated) limitations of the study design

Here’s how I see the discussion going:

1st Par. Main findings! Outline exactly what the reader should know.

2nd + Par. Go measurement by measurement and explain “at a smaller scale”

ONCE DONE, group effects (e.g. how does dist. Freq. affect forager behaviour), discuss while linking to literature

After, outline and discuss the limitations of the experiment. Mainly talk about small sample size, impossibility to distinguish anti-predator vigilance from looking for patches/at other foragers, etc

Last par. Repeat main findings and conclude discussion

EZ PZ, probably…

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Sentinel Presence | Proportion | Duration AB | Duration HD | Duration HU | Peck Rate | PTWY |
| Behaviour | X | NS | ↑ HD | X | X | X | X |
| Sentinel Presence | X | NS | ↑ Pres | NS | NS | NS | NS |
| Generalized Environment | NS | NS | ↑ Green | ↑ Green | NS | NS | ↑ F to A  Green |
| Disturbance Frequency | NS | X | ↓ as DF ↑ | ↓ as DF ↑ | NS | ↑ as DF ↑ | ↑ as DF ↑  F to A |
| Group Size | NS | X | NS | ↓ as GS ↑ | NS | NS | X |
| Bait Presence | X | X | NS | ↓ Pres | NS | ↑ Pres | Below |

Foraging to alert -> NS

Foraging to peck -> ↑

Alert to foraging -> Marginal ↑

Peck to alert -> ↑

MAIN FACTORS:

Neither the generalized environment, disturbance frequency, or group size affected the presence of a sentinel in the videos. We expected sentinel behaviour to be more present in green areas due to the assumed decreased ambient noise and longer lines of sight, yet these factors appear to not have played a part in sentinel decision-making, consistent with Bedneckoff’s state-dependent model. Sentinel crows could be deciding whether to perform sentinel behaviour primarily based off their energetic reserves, rather than the effectiveness of the behaviour in the environment. Disturbance frequency also did not affect the propensity of individuals to perform sentinel behaviour. Previous studies identified perceived risk as a factor in sentinel decision-making, with higher risk resulting in an increase in group sentinel effort.

Sentinel presence did not appear to affect the behaviour of foraging crows, with the only detected effect being the increase in duration of all behaviours.

Crows could be electing to not modify their behaviour, foraging in the most optimal manner for the individuals, and then receiving the benefits of additional vigilance offered by the sentinel when present. These benefits could differ among the two environments tested, resulting in the observed significant interaction between the generalized environment and the presence of a sentinel.

This is does not support my hypothesis and does not match the findings of other studies.

As for generalized environment, green areas increased the duration of all bouts, and bouts of foraging behaviour. In other words, crows spent a longer time being vulnerable in green areas than in commercial areas. This could be that the crows perceive their environment as safer, though it could also be that they require additional time to look for, manipulate, and consume food items in greener, grassier areas. The increased impermeable areas in commercial areas permit easier location and consumption of food. This is reinforced by the effects of bait presence, which decreases the duration of bouts of foraging behaviour, yet increases the peck rate of foragers. Conversely, peck rate was not affected by the generalized environment in which the individual forages in.

INTRO

There are environmental conditions that make sentinel behaviour less effective. For example, high noise levels in commercial areas would affect the communication between the sentinel and foragers. Ambient noise levels can muffle or disrupt sentinel vocalizations, forcing the sentinel to either make louder calls, thereby increasing its own exposure to predation risk, or to sentinel from locations closer to the foraging group, potentially increasing predator detection time. The inability of foragers to receive accurate information from the sentinel can also result in the foragers being more vigilant to compensate. This has been observed in sentinel species such as the dwarf mongoose

Behavioural adaptations could also reduce the need for the added protection of a sentinel. Urbanized individuals are less neophobic and are typically more tolerant of non-predator disturbances. While disturbance frequency could be higher in commercial areas, most of the disturbances are either anthropogenic or competition with other species for resources, rather than predation. As such, the perceived risk of urban commercial areas could be lower than in green areas where more predators could be present.

As a result, I would expect sentinels to be less present in commercial areas. Green areas will have longer lines of sight, less noise, and more predation risk than in commercial areas.

DISCUSSION

Outline:

**Summarize key findings**

Quickly introduce the effects detected of the main factors of interest

Sentinel behaviour had less of an impact on forager behaviour than initially predicted, with the only detected effect being the increase in duration of bouts of all behaviours when in the presence of a sentinel. Generalized environment on the other hand significantly affected the duration of bouts of foraging behaviour and the number of transitions from foraging to alert behaviours. Foraging in green spaces saw longer bouts of foraging behaviour, time spent being vulnerable, yet saw an increase in the number of transitions from the vulnerable to the alert state.

So the first thing I'd like to do when I'm talking about my discussion is going to be quickly introducing the effects detected kind of summarizing them an so originally when I got into this I really thought that there would be a huge impact of Sentinel behavior on the behavior of foragers well turns out it really didn't so this kind of goes in line with what I found out while doing my scoping review that Sentinel behavior might be much less of an altruistic behavior that I initially thought however generalized environment played a much more important role in the decision making of foragers with for example its affect on the duration of bouts of foraging behavior and the number of transitions from foraging to alert um in green spaces so there is a pretty big difference between green spaces and commercial areas which are again the two different types of environments that I was looking at green spaces saw longer bouts of foraging behavior so longer time spent being vulnerable yet saw an increase in the number of transitions from the vulnerable state to the alert state so clearly they are being yes Yep Yep Yep Yep Yep let's see here so green space is here so there was as we saw as I said earlier there was an increase in duration of foraging boats so compare here to there and then when it came to the number of transitions of going all the way down um we saw that from forging to alert we saw an increase in the number of bouts here which makes me think that environments are different and therefore it might take less time to be vulnerable let's say that so in other words they're spending longer times being vulnerable but they're switching to alert a little bit more often than then in other environments and well specifically in the commercial environment

Does this support the initial hypothesis and predictions?

It does not. So

does this support my hypothesis my initial hypothesis no it doesn't so a lot of my findings go pretty much contrary to my initial predictions and hypothesis which is a pretty fun finding for me um but let's get to that in a quick second because what I did find is that there are a number of other factors that are in some way may be related to the environment in which their foraging in that played a pretty big role in forger behavior specifically disturbance frequency group size and bait presence

Briefly introduce the effects of the other factors

Other factors such as the frequency of disturbances, bait presence, and group size significantly altered the behaviour of foragers. Now these factors definitely affected the behavior forgers so we can see for example bait presence affecting a number of the different measurements I took leading to an increase in pack rate for example here so for example in the presence of a bait the pack rate was actually substantially higher than in the absence of bait over here likewise a bunch of transitions were affected by the presence of bait oh and disturbance frequency as well so disturbance frequency affected the number of with what the literature would say with greater need for vigilance in situations where there's a higher risk of predation so that's kind of makes sense um but I would like to 1st talk about the two main factors that introduced earlier specifically central behavior and generalized environment so

**Effects of Sentinel Behaviour**

No big effects, even though literature would suggest a decrease in alert behaviour and increase in vulnerable time/foraging efficiency.

No effect on proportion: set pre-established need for each behaviour, therefore not changed much when it came to central behavior there were no significant effects on proportions so as I said earlier it could be that there's a set pre established need for the difference behaviors there's a need to be vulnerable to be vulnerable and foraging just as much as there's a need to be vigilant and aware for predators so that need could be relatively fixed in stone with the behavior varying more at the level of bouts which is what we saw when it came to the bout duration um

Variation in alert/foraging behaviour seen in duration of bouts and number of transitions (how often each behaviour is performed) when it came to the Boucher ation what we saw is an increase in duration of all bouts so going up a little bit so we saw an increase in the duration of all bouts but when we actually looked at different behaviors specifically forging alert behavior we thought that there was no significant effect of Sentinel behavior so this is again kind of weird but also kind of fits in line with the selfish state dependent model for central behavior where the individual that is asentinel makes a decision based on its own individual needs following the assumption that forging without asentinel is considerably more dangerous than being centinal and the benefits accrued from Sentinel behavior are go directly to the Sentinel itself with other you know the benefits of being able to detect predators earlier and the constant vigilance just being very fortunate byproducts of that behavior now what this can kind of be interpreted as is that the presence of asentinel essentially normalizes the response of foragers by kind of lessening the effects of the environment so when we look at forging behavior for example it appears that there's no real say when I looked at the post hoc comparisons between the different environments in the two states so in the presence of a central forgers and cleaners they had longer bouts but the difference in Boucher ation is much less so than in the absence of a Sentinel so it could be sort of like squishing together and mitigating some of these stressors mitigating some of these negative effects that would make the forge or need to spend more time being vigilant in the case of alert behavior it appears that there's sort of like a decrease as a result of sentence Sentinel presence in an increase in the time spent being alert in the absence of a Sentinel across the two different environments I'm still having a difficult time kind of understanding that effect but if we look at it in a more holistic manner again going back to the results of the linear mixed model there's no significant effects there's that significant interaction and if we look at the post hoc pairwise comparisons there was no significant difference between either presence of a Sentinel or commercial and the only significant intra didn't sort of difference was when you were comparing across the two different states I So what could potentially explain this so as I mentioned earlier it could be that Sentinels act in a selfish manner and that the benefits are Sentinel behavior or not necessarily for the other group members but more so for the protection and safety of the Sentinel itself uh that's kind of like the dead end that I'm at I can't really delve too I don't really know how else to sort of like divide and conquer this and sort of like rationalize it so I'm going to move on to generalized environment

Pivot: what explains this?

Could support the idea of sentinel behaviour as “selfish” as the benefits do not appear to be mainly to the foragers (did not significantly affect their behaviour)

Instead, it “normalized” the duration of bouts, potentially counteracting, or mitigating the stressors in the environment for example // other factors.

Supporting this, the interaction between sentinel behaviour and generalized environment was significant.

Sentinel behaviour in urban areas?

Likelihood of a sentinel in the videos unaffected by the generalized environment, supporting the theory that sentinel behaviour is a selfish decision.

**Effects of Generalized Environment**

Affected behaviours much more (than sentinel behaviour)

No need to repeat intro paragraph of discussion so generalized environment affected all behaviors much more the affected our measurements much more so than signal presence which kind of leads me to believe that they pay much more attention to the environment in which they are forging in rather than the presence or absence of asentinel um and so this can be kind of so I can kind of explain this by the differences between the two areas

Green space vs commercial area

Green space has longer sight lines, but requires more time to forage in / manipulate food, especially if not clumped together. So green spaces generally have much longer lines of sites but require more time to forage and more time to manipulate food specially if it's not sort of like clumped together in a dense patch so we saw much higher forging times in green spaces than in commercial spaces again this can be they take longer to look for the food to go through all the grass and to pack on stuff that they need to pack on uh kind of supporting this idea was the significant effect of bait so you might end up having so when I baited the sites I would have food on concrete much more visible which leads to a shortening in the time spent forging the the duration of parts of foraging behavior um

Leads to longer bouts of foraging behaviour and lower peck rate no OK kinda wanna stay on topic with the green spaces and generalized environment what we also observed in green spaces was that there was a decrease in the pack rate in green spaces to to do so in green spaces the back rate was substantially lower and again that could be because they are looking for food in grass on the other hand commercial areas are much more disturbed generally much more disturbed have shorter lines of sight or a louder there's going to be more stuff to need to pay attention to yet food is going to be typically more visible and also more densely clumped together for the simple reason that we as humans are decently messy creatures we leave our trash around so one of my favorite videos to code was in front of a Tim horton's where they were fighting over scraps of food up against a seagull so it kind of makes sense that the environment has a much more profound impact on the behavior of forgers and to kind of sort of support that we saw shorter bouts of forging and higher peccary in commercial areas

Commercial areas on the other hand are much more disturbed, chaotic, and with shorter lines of sight / louder, yet food is more visible and easier to forage on (especially on concrete)

Shorter bouts of foraging behaviour, higher peck rate

What about the effects on alert behaviour?

The duration of bouts of alert behaviour were unchanged, suggesting a set baseline for anti-predator vigilance at the individual level now the effects on alert behavior were that there was no significant effect on alert behavior caused by the environment in which they were foraging in suggesting that there is sort of a set baseline for antipredator vigilance anything lower is not good to answer the question no to be packing they needed to have their heads down and that means they are categorized as being vulnerable amusing this from previously done studies that were considering these two behaviors to be mutually exclusive uh so this the absence of effects on alert behavior would really kind of suggest that there's an individual need for alert for vigilance that cannot be really messed with anything lower is leads to increased risk of predation and anything higher being kind of non not necessary an you could be spending time feeding um so this kind of this kind of would make me think that social behavior in urban areas might be impeded or less effective or less required than in more rural areas even though the last cost opportunity the last opportunity cost of participating in Sentinel behavior would be mitigated by the quality of food in urban areas um this kind of supports this again kind of supports the idea that Sentinel behavior is a selfish behavior everyone's kind of out for themselves everyones being vigilant to the same amounts and not really paying attention to the presence of asentinel not decreasing their own personal vigilance in response to the presence of a visual of a vigilant Sentinel some other factors that could be affecting this could be stuff like risk tolerance so urban crows are going to be much more tolerant to human disturbances like simple pedestrians and vehicles so there they might be less likely to change their alert behavior unless the risk is very important and you can't really ignore it so for example up Raptor now anecdotally when Raptors did appear in our sampling sites they typically completely stopped all foraging activity and just started mobbing the Raptor and calling making a ton of noise or simply just abandoning the area so one of my favorite examples was when we were trying to get a site at Brock university and there was a pair of broadwing Hawks that decided to make a nest right in the Chapel at Brock and then there was sort of like a Canadian standoff where there was like 7 crows on one rooftop and two broadwing Hawks on the other rooftop just sort of watching each other and since then I wasn't able to sort of see any crows at that location which kind of sucks but kind of supports the idea that there's kind of a risk reward sort of trade off that the crows are paying attention to where if the risk are too high if the risk are not really worth the reward and if you're in an environment where foraging opportunities are quite abundant then it might just be worthwhile just abandon the area and not come back uh so that's kind of what I saw on a number of different occasions um excuse me I'm just gonna quickly by my nose are there any questions up until now moving on um quickly to talk about the effects of the other factors that I I measured so **those were again just to repeat disturbance frequency bait presence and group size so**

Could be that factors make sentinel less effective, therefore less reliance on it

Again, kind of supporting the idea that the benefits of sentinel behaviour are primarily to the sentinel, not the group

Other factors affecting this outcome

Tolerance of risks and human proximity

More risk tolerant = less likely to see changes in alert behaviour unless risk is important, e.g. predator.

Risk vs. reward

If environment too risky and foraging opportunities abundant, may be better to abandon location and find other sources of food.

Anecdotally, when raptor appeared or when disturbed by pet (not pedestrian or vehicle), more likely to abandon location.

**Effects of other factors**

**Disturbance Frequency**

Higher disturbance freq led to decrease in bouts of all behaviours and bouts of foraging, yet increased peck rate um disturbance frequency led to a decrease in the duration of bouts of all behaviors yet increased the pack rate so quickly going to go up here so there was a decrease in the duration of all behaviors as seen here more so in the duration of foraging behavior as seen there and in the graph here again there's some issues with the not the stats but it's hard to make inclusive statements here but there is a negative trend it is apparently statistically significant and in the case of pet crate we saw that the Peck rate increased as disturbance frequency increased now this might seem counter intuitive but it kind of makes sense especially if you consider the risk allocation hypothesis so risk allocation hypothesis is if there's a period of time where it's kind of risky you're going to abstain from foraging but as soon as the risk is away going to drop down and you're going for it and oftentimes you're going forward in a much higher foraging efficiency for the simple reason that the risk is away now now is the time to eat so it's essentially when the cats are out the mouse come out to play but in this case it's when the pedestrians out of the 5m area of the crows come down to eat it's very very hard to sort of disentangle this from the environment so again different environments are going to have different frequencies of disturbances and different types of disturbances so it is going to be important to sort of state that at least for me in the discussion that disturbance frequency and generalized environments cannot be taken separately if that kind of makes sense the next factor I want to discuss is going to be bait presence and it's truly one of the more interesting findings that I found so to quickly to quickly hold on I need to put my words in order it comes to bait presidents bait was essentially A proxy or could be considered a proxy for just general litter in the environment uh so as humans were decently Massey there's obviously people that are messier than others and who just dropped their stuff wherever they finish it you know Packer fries some hamburger bits here chicken Nuggets whatever in my case it was Jesus now these litter can essentially be considered a very very dense patch of very high energy food which is what my bait was and turns out that there's quite a few significant effects of the presence of bait on the behavior of forges so it increased Peck rate and decreased forging time which actually means it's more effective free to forage on litter because it's safer safer in the sense that it takes less time for you to pack at eat the food but also contains generally more calories than any type of natural foods so again you consider a pack of fries that might have you know 500 calories in like a handful of fries I'm exaggerating a lot but you know there's a decent amount more calories in fries than there are in berries or I mean if you look at the time it takes for you to find an then hunt down a mouse for example mouse might have the same caloric value and potentially more nutritional value than than some fries but it is much harder to hunt a mouse than it is to just swooped down and eat some fries so that could be something that needs to be followed up on there has been some studies that actually looked at the preference of urban crows of what types of food that they turns out that they will prefer anthropogenic foods potentially for that simple reason that it's easier and safer free to forage on I so again that's that's kind of an interesting finding for me that's finding that I was kind of not expecting to be as significant as it was I I put it in there just as a sort of control factor just to make sure you know if there is a difference in terms that there was a really really big difference and you're going to have again you might have some hold on let me the presence of litter is going to be again dependent on the type of environment that you're in if you were to be in a natural environment you might not find natural or you know less urbanized less developed land you will find less litter less of these high density patches of food then in for example right next to a Tim horton's so that's definitely something that needs to be followed up on last but not least group size so group size is expected to decrease individual vigilance while increasing overall vigilance so this could be either through the many eyes hypothesis or through simple prey dilution but there's you know countless examples of this in the literature that as group size increases individual vigilance decreases turns out that kind of not really um So what we did observe was that as group size increased the duration of boats actually decreased let me find that no that's not it so as group sized excuse me as group size increased the duration about decreased that's weird I have to go back to that ha um the exact opposite unless to go back to this got this so yeah the different types of disturbances so again I did look at the I did categorise the different types of disturbances per video and the current disturbances are the overall disturbances per foraging time but it would be an interesting approach to actually see whether or not there's a significant difference in the type of disturbances per area click dictation I don't know where the mouse is OK so if i click

A sense of urgency – Lima, risk allocation hypothesis

Forage when risk is away, back off when risk is present.

Related to generalized environment, as environments are not equal in how and how often they are disturbed.

**Bait Presence**

Truly one of the most interesting finding.

Bait used can be a proxy for litter or trash found in the environment. Always on concrete, so the contrast between baited and unbaited sites can be weird as not all unbaited sites were on concrete, but all baited sites had food on concrete.

Bait increased peck rate and decreased foraging time, meaning that foraging on bait or potentially litter is both more effective and safer (as it requires less time and generally is more calorically high).

Typically will require less handling time, and less time required to find the food, especially in grassy areas.

**Group Size**

Is expected to decrease individual vigilance while increasing overall vigilance (provide references, but easy to find)

Observed effect is that as group size increases, the duration of bouts decrease.

Verry curious, since literature would suggest otherwise

Could be that interspecific competition increases in urban areas (although it shouldn’t, it is a good area to look into for future studies)

Safer in greater numbers, but cost of social behaviour (group foraging)

**Discussion of unexpected results**

My findings do not line up with those of previous studies.

While some findings support some hypotheses, namely the state-dependent model for sentinel behaviour, they do not fully support findings about adaptations to urbanization.

**Limitations and weaknesses**

Low sample size make making conclusive statements difficult to make based on the currently available data.

Sampling in a non-urban area or even a natural area as a control would be a good method of distinguishing the adaptations associated with urbanized birds vs less urbanized birds.

Impossible to actually ascertain what the crows are being vigilant for, either sources of threat or other members

**Potential follow-up studies**

As mentioned earlier, looking at aggression in urbanized crows

Also a potentially interesting study would be to determine if there are genetic differences between more or less urbanized crows, then verify if it correlates with changes in social behaviour.

**Restatement of most significant findings and their implications**

**I think I bit my tongue like 6 times during that entire thing like I don't know what it is I've been my tongue while sleeping and it's just my my left side of my tongue is just like on fire right now so so this for example is one of those plots that's the findings that I'm having a harder time sort of interpreting and it's this significant effect of Sentinel behavior and generalized environment where there's two opposing you know there's two opposing directions in green spaces I would expect potentially that alert behavior would decrease literation of time spent being alert on average per bout for the simple reason that you have longer lines of sight and therefore it shouldn't take as long to actually look around see OK there's nothing around me all right let's go not being said it could be the opposite as seen here in the absence of a Sentinel where individuals are more reliant on their own individual vigilance it could be that because the lines of sight are longer not they need more time to truly sort of look around and then see whether or not there is something out there I again that's really weird for me why it's sort of like across here it could be that Sentinel is taking care of it and the foragers are just like OK cool the sentence there that doesn't really line up with the rest of the results said something really that I wanted to I've always had a hard time really interpreting interactions**

**Structure Pt. 2**

**Introduction and Summary of Key Findings**

Briefly introduce the study and summarize the main findings.

Our study sought to investigate how generalized environment (green areas vs. commercial areas), and the presence of a sentinel disturbance frequency 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 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 safer, even though they spend more time being vulnerable. Yet, we did not find any significant effects, apart from increasing the duration of all behaviours, of sentinel presence on the behaviour of foragers. We found that 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 the environmental factors studied. The presence of a sentinel also did not significantly affect the behavior of foraging crows, except for an increase in the duration of all behaviors. Our results 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 safer, even though 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 environmental conditions.

**Sentinel Behavior**

Discuss the lack of significant effects of sentinel behavior on forager behavior.

The lack of significant effects of sentinel behavior on forager behavior in the study is an intriguing finding that challenges traditional notions of sentinel behavior in group-living animals. The results suggest that sentinel crows may not significantly influence the behavior of their fellow foragers, at least in the contexts studied. This finding contrasts with expectations and previous studies that suggested sentinel behavior would lead 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 as a whole. The study's results may support Bedneckoff's state-dependent model, which proposes that individuals make decisions based on their own energetic needs and the benefits they receive from certain behaviors.

Another interpretation could be that the benefits of sentinel behavior are not easily discernible at the group level. While sentinels may provide increased vigilance and predator detection, the individual foragers may not alter their behavior significantly in response to the sentinel's presence. This could suggest that the benefits of sentinel behavior are more subtle or indirect, such as providing a sense of security that allows foragers to focus more on foraging without actively reducing their vigilance.

Overall, the lack of significant effects of sentinel behavior on forager behavior opens up new questions about the function and evolution of sentinel behavior in crows. Further research could explore the underlying mechanisms and benefits of sentinel behavior in more detail to gain a deeper understanding of its role in group-living animals.

Consider the implications of this finding and how it relates to previous studies and hypotheses.

The finding that sentinel behavior in crows did not significantly affect the behavior of foragers has several implications for our understanding of cooperative behavior in animals. Firstly, it suggests that sentinel behavior may not always function as a cooperative strategy to benefit the group as a whole. Instead, it may be more self-serving, with individual sentinels primarily benefiting from the increased vigilance and predator detection.

This finding challenges previous hypotheses that suggested sentinel behavior would lead to a decrease in alert behavior and an increase in foraging efficiency for the group. It suggests that the relationship between sentinels and foragers may be more complex and nuanced than previously thought.

The study's results also have implications for our understanding of group decision-making and coordination in animals. They suggest that the behavior of individual group members may be more influenced by internal factors, such as energetic needs, than by external factors, such as the presence of a sentinel. This highlights the importance of considering individual differences and motivations when studying group behavior.

Overall, this finding adds to our understanding of the diversity of cooperative strategies in animals and emphasizes the need for further research to uncover the underlying mechanisms and evolutionary implications of sentinel behavior in crows and other group-living species.

Interpret the results in light of Bedneckoff’s state-dependent model.

Bednekoff’s state-dependent model posits that individuals make decisions about engaging in sentinel behavior based on their own energetic reserves and the potential benefits of the behavior. In the context of the study's findings, the lack of significant effects of sentinel behavior on forager behavior could be interpreted in line with this model.

The results suggest that sentinel crows may be making decisions about engaging in sentinel behavior based on their own individual needs rather than the needs of the group. This is consistent with the idea that sentinel behavior may be more self-serving, with the primary benefits accruing to the sentinel itself. The increased vigilance and predator detection provided by sentinel behavior may directly benefit the sentinel in terms of increased safety and access to resources.

Additionally, the lack of significant effects of sentinel behavior on forager behavior may suggest that the benefits of sentinel behavior are not easily shared among group members. For example, while a sentinel may provide increased vigilance for the group as a whole, individual foragers may not alter their behavior significantly in response to this increased vigilance. This could be because the benefits of sentinel behavior are not easily discernible at the group level or because individual foragers are more focused on their own immediate needs and priorities.

Overall, interpreting the results in light of Bednekoff’s state-dependent model suggests that sentinel behavior in crows may be driven more by individual needs and motivations than by group-level benefits. This highlights the complexity of cooperative behavior in animals and the need for further research to understand the underlying mechanisms and evolutionary implications of sentinel behavior.

**Generalized Environment**

Highlight the significant effects of the generalized environment on forager behavior.

The study 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. Specifically, in green areas, crows exhibited longer bouts of foraging behavior, indicating that they spent more time actively searching for and consuming food. This suggests that crows perceived green areas as safer environments for foraging, despite potentially longer lines of sight and increased predation risk.

Furthermore, in green areas, there was an increase in the number of transitions from the vulnerable state to the alert state. 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.

These findings highlight the importance of the environment in shaping forager behavior. Green areas, with their longer lines of sight but potentially higher predation risk, led to different foraging strategies compared to commercial areas, which were more disturbed but offered easier access to food. This demonstrates the adaptability of crows in different environments and suggests that they may adjust their behavior based on the perceived risks and rewards of each environment.

Discuss how green areas and commercial areas differ in terms of foraging behavior.

Green areas and commercial areas differ significantly in terms of foraging behavior in crows, as observed in the study. Green areas, such as parks or natural habitats, offer longer lines of sight, less ambient noise, and potentially higher predation risk compared to commercial areas, such as urban settings or areas with human activity.

In green areas, crows exhibited longer bouts of foraging behavior, suggesting 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. Additionally, crows in green areas showed an increase in the number of transitions from the vulnerable to the alert state, indicating higher vigilance and awareness of potential threats.

In contrast, commercial areas, while more disturbed and with shorter lines of sight, offered easier access to food. Crows in commercial areas exhibited shorter bouts of foraging behavior but a higher peck rate, suggesting that they were able to locate and consume food more quickly and efficiently in these environments. This could be due to the presence of human-generated litter or food scraps, which provide easily accessible and high-energy food sources.

Overall, the differences in foraging behavior between green areas and commercial areas reflect the trade-offs that crows make in different environments. In green areas, crows may spend more time foraging but also need to be more vigilant due to higher predation risk. In commercial areas, foraging may be more efficient but also requires navigating human disturbances and potential competition for food.

Consider the implications of these findings for understanding crow behavior in different environments.

These findings have several implications for understanding crow behavior in different environments. Firstly, they highlight the adaptability of crows to varying environmental conditions. Crows in green areas and commercial areas exhibited different foraging strategies, suggesting that they are able to adjust their behavior based on the specific challenges and opportunities presented by each environment. This adaptability may be crucial for crows to thrive in a wide range of habitats, from urban areas to natural landscapes.

Secondly, the findings suggest that crows may prioritize different aspects of their behavior in different environments. In green areas, where predation risk may be higher, crows may prioritize vigilance and spend more time being alert. In commercial areas, where food availability may be higher but disturbance levels are also higher, crows may prioritize efficient foraging to maximize their food intake.

Additionally, these findings have implications for our understanding of urban ecology and the role of crows in urban ecosystems. Crows are known to be highly adaptable to urban environments, and these findings suggest that they are able to adjust their behavior in response to the unique challenges and opportunities presented by urban areas. Understanding how crows navigate urban environments can provide valuable insights into how wildlife adapts to human-dominated landscapes and can inform conservation efforts in urban areas.

Overall, these findings highlight the complexity of crow behavior and the importance of considering environmental factors when studying animal behavior. They suggest that crows are able to tailor their behavior to suit their environment, demonstrating the remarkable flexibility and adaptability of these intelligent birds.

**Interactions Between Factors**

Discuss the significant interaction between sentinel behavior and the generalized environment.

The study found a significant interaction between sentinel behavior and the generalized environment, which provides valuable insights into how crows' behavior is influenced by both internal factors (such as energetic reserves) and external factors (such as the environment). This interaction suggests that the effects of sentinel behavior on forager behavior are not uniform across different environments, highlighting the complexity of group dynamics in crows.

In green areas, where predation risk may be higher, the presence of a sentinel did not significantly affect forager behavior. This suggests that in these environments, individual foragers may already be highly vigilant and alert, regardless of the presence of a sentinel. In contrast, in commercial areas, where predation risk may be lower but disturbance levels are higher, the presence of a sentinel led to longer bouts of foraging behavior and a decrease in the number of transitions from the vulnerable to the alert state. This suggests that in commercial areas, the presence of a sentinel may provide a sense of security for foragers, allowing them to spend more time foraging and less time being vigilant.

Overall, this interaction between sentinel behavior and the generalized environment highlights the importance of considering both internal and external factors when studying group dynamics in crows. It suggests that the effects of sentinel behavior on forager behavior are context-dependent, and may vary depending on the specific challenges and opportunities presented by different environments. Understanding these interactions can provide valuable insights into the adaptive significance of sentinel behavior and the role it plays in group living in crows.

Consider possible explanations for this interaction, such as the selfish nature of sentinel behavior.

One possible explanation for the interaction between sentinel behavior and the generalized environment is the selfish nature of sentinel behavior. The study's findings suggest that the presence of a sentinel primarily benefits the sentinel itself, rather than the group as a whole. This aligns with the idea that sentinel behavior is a selfish behavior, where individuals act in their own self-interest rather than for the benefit of the group.

In green areas, where predation risk is higher, individuals may be more motivated to act as sentinels to protect themselves from potential threats. In this context, the benefits of sentinel behavior, such as increased vigilance and early detection of predators, may outweigh the costs for the individual sentinel. As a result, the presence of a sentinel may not significantly affect forager behavior, as individuals are already highly vigilant and alert due to the perceived higher predation risk.

In contrast, in commercial areas where predation risk is lower but disturbance levels are higher, the benefits of sentinel behavior may be less pronounced. Individuals may be less motivated to act as sentinels, as the perceived risks are lower and the benefits may not outweigh the costs. In this context, the presence of a sentinel may provide a sense of security for foragers, allowing them to spend more time foraging and less time being vigilant.

Overall, the selfish nature of sentinel behavior may explain the interaction observed in the study, where the effects of sentinel behavior on forager behavior vary depending on the specific challenges and opportunities presented by different environments.

**Effects of Other Factors**

Briefly discuss the effects of disturbance frequency, bait presence, and group size on forager behavior.

Disturbance frequency, bait presence, and group size all had significant effects on forager behavior in the study.

Disturbance Frequency: 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.

Bait Presence: 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.

Group Size: Contrary to expectations, as group size increased, the duration of bouts of all behaviors decreased. This finding is surprising, as previous studies suggest that larger group sizes should decrease individual vigilance while increasing overall vigilance. Further research is needed to understand why this relationship was not observed in the study.

These findings highlight the complex interplay between environmental factors and forager behavior in crows. They suggest that crows adjust their behavior in response to various factors, such as disturbance frequency, food availability, and group size, to optimize their foraging efficiency and minimize risk.

Consider how these factors may influence the effectiveness of sentinel behavior.

These factors may influence the effectiveness of sentinel behavior in several ways:

Disturbance Frequency: Higher disturbance frequency may make it more challenging for sentinels to effectively communicate with foragers. Increased noise levels or frequent disruptions could interfere with sentinel vocalizations, reducing their ability to warn the group of potential threats. This could decrease the overall effectiveness of sentinel behavior in detecting and deterring predators.

Bait Presence: The presence of bait or other high-density food sources may influence the motivation of individuals to act as sentinels. If food is abundant and easily accessible, individuals may be less inclined to take on the role of sentinel, as the benefits of sentinel behavior may be lower compared to environments with scarce food resources. This could result in fewer individuals exhibiting sentinel behavior, reducing the overall effectiveness of sentinel surveillance.

Group Size: The size of the group may impact the effectiveness of sentinel behavior. In larger groups, there may be more individuals available to act as sentinels, increasing the likelihood that at least one individual is vigilant at any given time. However, larger groups may also experience increased competition for the sentinel position, which could reduce the overall effectiveness of sentinel behavior if individuals are less motivated to actively perform the role.

Overall, these factors can influence the dynamics of sentinel behavior within a group, affecting its overall effectiveness in detecting and responding to potential threats. Understanding how these factors interact with sentinel behavior can provide valuable insights into the adaptive significance of sentinel behavior in group-living species like crows.

**Discussion of Unexpected Results**

Highlight any findings that do not align with previous studies or hypotheses.

Several findings from this study do not align with previous studies or hypotheses:

Sentinel Behavior: Contrary to expectations, the study found that sentinel behavior did not significantly affect the behavior of foragers. Previous studies suggested that sentinel behavior would lead to a decrease in alert behavior and an increase in vulnerable time or foraging efficiency. However, the study found no significant effects of sentinel behavior on these behaviors, indicating that sentinel behavior may not have a strong impact on forager behavior in crows.

Effects of Generalized Environment: The study found that the generalized environment had a significant impact on forager behavior, with green areas and commercial areas showing distinct patterns. In green areas, crows spent longer bouts of foraging behavior and more time being vulnerable, but also had more transitions from the vulnerable to the alert state. This contrasts with previous studies that suggested crows would exhibit less vigilant behavior in green areas due to longer lines of sight and perceived lower predation risk.

Group Size: The study found that as group size increased, the duration of bouts of all behaviors decreased. This finding is contrary to the expected pattern, where larger group sizes would decrease individual vigilance while increasing overall vigilance. This discrepancy suggests that the relationship between group size and vigilance behavior may be more complex than previously thought.

These findings highlight the importance of considering the specific context and environmental conditions when studying animal behavior. They suggest that the effects of sentinel behavior and other factors on forager behavior may vary depending on the unique challenges and opportunities presented by different environments.

Consider possible explanations for these unexpected results.

There are several possible explanations for the unexpected results observed in the study:

Sentinel Behavior: The lack of significant effects of sentinel behavior on forager behavior could be due to the state-dependent nature of sentinel decision-making. According to Bednekoff's state-dependent model, individuals may decide to act as sentinels based on their own energetic reserves and perceived risk, rather than the effectiveness of sentinel behavior in the environment. If individuals are making decisions about sentinel behavior based on their own needs rather than group benefits, this could explain why sentinel behavior did not significantly affect forager behavior in the study.

Effects of Generalized Environment: The unexpected effects of the generalized environment on forager behavior could be due to differences in resource distribution and predation risk between green areas and commercial areas. In green areas, crows may need to spend more time foraging and being vigilant due to the dispersed nature of food resources and higher predation risk. In contrast, commercial areas may offer more concentrated food sources and lower predation risk, allowing for more efficient foraging behavior. These differences could explain why crows exhibited longer bouts of foraging behavior and more transitions from the vulnerable to the alert state in green areas compared to commercial areas.

Group Size: The unexpected effects of group size on forager behavior could be due to increased competition for resources in larger groups. While larger groups may provide more eyes to detect predators, they may also lead to increased competition for food. This could result in shorter bouts of foraging behavior as individuals prioritize obtaining food quickly over vigilance behavior. Additionally, larger groups may experience more disturbances, which could also contribute to shorter bouts of behavior.

Overall, these explanations suggest that the relationships between sentinel behavior, environmental factors, and forager behavior are complex and context-dependent. Further research is needed to fully understand the mechanisms underlying these unexpected results.

**Limitations and Weaknesses**

Acknowledge the limitations of the study, such as the sample size and the difficulty of interpreting certain results.

The study has several limitations that should be acknowledged. Firstly, the sample size of the study may have limited the ability to detect significant effects. While efforts were made to collect a sufficient number of observations, the complexity of the behaviors being studied and the variability in environmental conditions may have influenced the statistical power of the analyses. As such, caution should be exercised when interpreting the results, and further studies with larger sample sizes are warranted to validate the findings.

Additionally, the study focused on a specific population of crows in particular environments, which may limit the generalizability of the results to other populations or environments. Factors such as local food availability, predation pressure, and social dynamics can vary widely between populations, and these factors may influence the behaviors observed in this study. Therefore, caution should be taken when extrapolating these findings to other crow populations or species.

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.

Overall, while the 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 the complexities of crow behavior.

**Potential Follow-up Studies**

Suggest possible follow-up studies, such as examining aggression in urbanized crows or investigating genetic differences between urban and less urbanized crows.

There are several potential follow-up studies that could build upon the findings of this study:

Aggression in Urbanized Crows: Investigating the levels and patterns of aggression in urbanized crows could provide further insights into how urban environments influence social behavior. This could involve observing interactions between crows in different urban settings and comparing them to interactions in less urbanized areas.

Genetic Differences between Urban and Less Urbanized Crows: Examining whether there are genetic differences between crows living in urban environments and those in less urbanized areas could help determine if there are genetic adaptations associated with urbanization. This could involve genetic sequencing of crows from different populations to identify any genetic markers associated with urban living.

Effects of Noise Pollution on Sentinel Behavior: Given the lack of significant effects of sentinel behavior observed in this study, further research could investigate the impact of noise pollution on sentinel decision-making. This could involve experimental studies in which crows are exposed to varying levels of noise to see how it affects their vigilance behavior.

Longitudinal Studies of Crow Behavior: Conducting longitudinal studies to track changes in crow behavior over time could provide valuable insights into how urbanization and other environmental factors influence behavior. This could involve monitoring the same population of crows over multiple years to observe any changes in behavior patterns.

Overall, these follow-up studies could help further our understanding of how crows adapt to urban environments and shed light on the complex interactions between behavior, genetics, and the environment.

**Restatement of Most Significant Findings and Their Implications**

Summarize the most significant findings of the study and discuss their implications for understanding crow behavior.

The study investigated the effects of sentinel behavior and the generalized environment on the behavior of foraging crows in different urban environments. The most significant findings include:

Sentinel Behavior: 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.

Generalized Environment: 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.

Interaction Effect: There was a significant interaction between sentinel behavior and the generalized environment. This suggests that the presence of sentinels may normalize the response of foragers, mitigating the effects of environmental stressors and potentially enhancing foraging efficiency.

Other Factors: 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 highlights 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.