**Introduction**

**Discussion**

**Intrinsic Factors:**

Our review identified several intrinsic and extrinsic factors that can influence sentinel behavior in avian and mammal species. The common intrinsic factors tested were sex, maturity, body mass and satiation. The effects of sex were consistent throughout species, with males engaging in sentinel behaviour more than females The difference in sentinel behaviour could be attributed to differences in energetic investment between sexes, with males having more energy available for activities outside of reproduction. Male reproduction is less energetically costly than in females (sperm vs. egg production) which would result in additional energy able to be allocated towards other behaviours including sentinel behaviour. This is especially true during the breeding season when females could be investing considerable amounts of time and energy into caring for young. In red-winged blackbirds (*Agelaius phoeniceus*), males assume the role of nest guarding through sentinel behaviour, with nest success associated with closer and higher perches. Likewise in Zebra finch, sentinels, which were most often males, alerted their partners when threats approached the nest, resulting in incubating individuals flushing their nests earlier than when sentinels were absent. The benefits from sentinel behaviour could therefore extend past increased foraging efficiency and increased biomass intake, but also to increased nest success and mate survival.

Sentinel behaviour could also play a role in male intrasexual competition over mates and territories. When encountering a foreign male’s solo song, dominant male white-browed sparrow weavers (*Plocepasser mahali*) increased their sentinel effort despite already sentineling more than other group members. The increased sentinel behaviour of dominant male individuals could be to detect and gather information about the intruding individual. The use of sentinel behaviour for non-antipredator vigilance is also observed in mammal species. When encountering signs of rival groups, dwarf mongoose (*Helogale* parvula) more regularly engaged in sentinel behaviour to gather more information about the threat. Since dominant males are most often usurped by out-group individual rather than subordinates, early detection and monitoring of rivals is essential for dominant males to maintain their position in the group. This interaction between sex and dominance, an extrinsic factor, is often reported in studies, with dominant males sentineling more than other group members. Consistent with the hypothesis of differing energetic investment between sexes, subordinate males sentineled more than subordinate females in both mammal and avian species.

Another intrinsic factor identified in our review was maturity. Older and more experienced individuals sentineled more than younger individuals. Younger individuals could be inefficient sentinels as they lack the experience to identify potential threats. The misidentification of a threat could result in mortality or to unnecessary energetic expenditure. If a threat is undetected by the sentinel, foragers could be at greater risk of predation due to their reliance on the sentinel’s vigilance, resulting in injury or death. Though less detrimental to an individual’s immediate survival, inappropriate alarm calls are detrimental to foraging efficiency and diminish the benefits provided by sentinel behaviour. Correct identification of threats is therefore crucial for effective sentinel behaviour. Older individuals could have had greater exposure to potential threats present in the environment and can better recognize and vocalize the presence of a threat. Younger individuals could also take advantage of the sentinel behaviour of more experienced individuals to learn to identify threats. Social learning helps mitigate the costs of learning about threats by reducing the risk of injury or mortality of learning through direct exposure to danger.

Older and more experienced individuals could also have greater energetic resources to allocate to sentinel behaviour. Mature adults could have more efficient foraging strategies and no longer need to allocate as much energy to growth and development, reducing the costs of performing sentinel behaviour. In comparison, maturing young could have a different allocation of energy and could be less capable of spending energy being sentinel and instead favouring foraging to compensate for the lower foraging efficiency and their growth.

Energetic resources therefore play a considerable role in an individual’s decision to perform sentinel behaviour. The selfish state-dependent model proposes that an individual will perform sentinel behaviour if the alternative is foraging without a sentinel present, a considerably more dangerous option. However, sentinel behaviour is only favourable if the individual has sufficient energetic reserves to perform this behaviour. The results of studies on the effects of satiation and body mass on sentinel behaviour are consistent with this hypothesis, with heavier and more satiated individuals sentineling more than lighter, unsatiated individuals. Sentinel behaviour is unfavourable for individuals lacking sufficient energetic levels to perform it as the long periods of vigil are lost foraging opportunities for the individual. Instead, it would be most beneficial to forage quickly and maintain sufficient individual vigilance to limit the risk of predation. Individuals capable of more efficient foraging, achieving the minimal energetic threshold to perform sentinel behaviour quicker than other individuals, therefore sentinel earlier and more than other group members. This was supported by the results of studies on dwarf mongoose and, Arabian babblers (*Turdoides squamiceps*), and Florida scrub-jays (Aphelocoma coerulescens) which found that fed individuals often immediately commenced sentinel behaviour. Satiated individuals also decreased their foraging behaviour and sentineled more and longer than unsatiated individuals. In response to the increased sentinel behaviour of a group member, other members compensated and decreased their own sentinel behaviour. These findings suggest that upon achieving sufficient energetic reserves, sentinel behaviour could be the most beneficial activity for the individual.

Originally believed to be a selfless behaviour, sentinel behaviour as explained by the state-dependent model for sentinel decision-making could be a result of selfish decisions made by the individual to satisfy their personal needs. The energetic state of the individual appears to be trade off for increased the increased individual safety provided by sentinel behaviour. When under risk of predation, sentinels could identify threats and reach a safe refuge earlier than foragers. Intrinsic factors identified by our review can affect the energetic investment and reserves of individuals, altering their behaviour. Though the benefits of sentinel behaviour are mainly antipredator vigilance, dominant males could have ulterior motives for performing the behaviour, further altering their propensity to perform sentinel behaviour.

**Extrinsic Factors:**

Our review has also identified several extrinsic factors that can affect sentinel behaviour. Dominance, group size, and risk play significant roles in shaping sentinel behavior in mammal and avian species. These factors influence sentinel decision-making often in conjunction with intrinsic factors. Social hierarchies within groups can significantly affect sentinel behaviour, with dominant individuals sentineling more than subordinates. Dominant individuals could have greater access to resources, either through more effective foraging strategies or receiving gifts from other members of the group, reducing the lost foraging opportunity cost of performing the behaviour. The differences in sentinel behaviour between dominant and subordinate individuals could also reflect the differences in benefits received by the sentinel. Dominant, usually male, individuals could also be using the behaviour for non-antipredator benefits, but instead to guard against outgroup rivals and territory intrusions as previously discussed. Subordinates do contribute to a group’s sentinel behaviour but could be compensating for the dominant individual’s sentinel behaviour by reducing theirs. When fed however, subordinate Arabian babblers increased the duration of their sentinel bouts significantly more than dominants in comparison to when unfed, indicating they ended their bouts with a lower energetic state than dominants. This could point to yet another difference in energetic investment among group members, causing a difference in their individual contribution to the group’s sentinel behaviour.

The effects of group size on sentinel behaviour are not surprising. The greater the number of group members, the greater the likelihood of an individual having sufficient energetic reserves to sentinel. Larger groups will therefore see decreased individual sentinel behaviour but more sentinel behaviour at the group level, with fewer and shorter gaps between bouts of sentinel behaviour. In smaller groups, individuals must perform longer bouts of sentinel behaviour, increasing costs of sentinel behaviour for participating group members. Though, larger groups can result in increased competition for limited resources, possibly increasing the reliance on the added vigilance of the sentinel during scramble competition. Larger groups can more effectively distribute the costs of sentinel behaviour among members, while also providing other predation risk-reducing effects through other group-size effects such as the Many Eyes hypothesis.

Increased risk had similar effects on the sentinel behaviour of avian and mammal species, where increased sentinel behaviour was observed in situations of heightened risk. This risk can be from the presence of predators but also the presence of outgroup rivals and territory intruders, which caused an increase in sentinel behaviour. The collection of information on potential threats is essential to the survival of individuals. Earlier detection of predators can reduce the risk of mortality and injury because of an interaction with a predator, increasing survival of group members and mates. The presence of at-risk individuals, such as young individuals, also resulted in an increase in sentinel behaviour, likely to compensate for an increase in predation risk. In meerkats (*Suricata suricatta*), the presence of pups significantly increased the sentinel behaviour of subordinates during foraging trips. The presence of young in the group could increase predation risk if young individuals are more vulnerable or have inefficient vigilance due to a lack of experiences with threats. Their inclusion in foraging groups could therefore increase the group’s risk of predation, resulting in increased sentinel behaviour in adult members. Reduced risk environments, such as in captivity, have shown that captive meerkats behaved similarly to their wild counterparts suggesting that sentinel behaviour is plastic, but does not disappear in the absence of predation risk. Instead, individuals could be upregulating their sentinel behaviour in response to increased perceived threat but maintain a ‘baseline’ level of sentinel behaviour in times of low risk, further supporting the hypothesis that the behaviour is dependent on the selfish motivation of individuals.

Extrinsic factors can also modify the effectiveness of the sentinel, diminishing the benefits provided to the non-sentinel individuals. Factors such as access to adequate sentinel locations, anthropogenic noise and factors that increase environmental uncertainty such as visual obstructions (e.g. tall grasses), shorter lines of sight and novel stimuli can also alter an individual’s need for vigilance and by extension sentinel behaviour. In dwarf mongoose, the presence of anthropogenic noises significantly affected the ability to hear acoustic signals from the sentinel, reducing their effectiveness. Foragers were observed to increase their personal vigilance in response to compensate. The wealth of environmental factors that can increase the anxiety and need for vigilance require further study to assess their impacts on sentinel behaviour.

The likelihood of an individual to perform sentinel behaviour can therefore be affected by extrinsic as well as intrinsic factors, revealing a remarkably plastic behaviour. By altering changing their behaviour, individuals can best manage their own needs for foraging and vigilance based on their energetic reserves and the perceived threats in their environments. This ability to alter their behaviour can be adaptive in highly variable environments. While the benefits are primarily to the sentinel, either increased safety or increased ability to gather information, the presence of a sentinel is advantageous to other group members. Foragers could gain increased biomass intake and foraging efficiency while lowering their risk of predation, thereby increasing the success of sentinel species.

**Coordination of Sentinel Behavior:**

Coordination of sentinels has been identified as the defining feature of true sentinel systems. The adoption of an exposed prominent position from which to perform constant vigilance, and the communication of threats through alarm calls are not behaviours exclusive to sentinel behaviour. These characteristics can not be solely relied upon to describe a sentinel species. Instead, the coordination of sentinel bouts to ensure no overlap and reduce gaps should then appear more frequently in contemporary literature on sentinel behaviour. Despite this, there is a low number of articles that explicitly mention coordination in their definition of sentinel behaviour, though an upward trend is detected in articles published after 2017. However, this is not accompanied by a decrease in the number of articles without this criterion. By not including and testing for the coordination of sentinels, we are exposing ourselves to increased risk of misidentification of sentinel species. The correct identification of sentinel systems is required to further our understanding of the underlying mechanisms behind these complex social behaviours.

**Exploration of Urbanization Effects:**

Explore the potential effects of urbanization on sentinel behavior using the factors identified in the review.

Urbanization can have significant effects on sentinel behavior in animal populations. Several factors identified in the review can help us understand these potential effects:

Satiation and Body Mass: Urban environments often provide abundant food sources, leading to increased satiation and potentially higher body mass in urban-dwelling animals. This could result in reduced motivation to perform sentinel behavior, as individuals may feel less need to forage vigilantly when food is plentiful.

Sex: Urban environments can alter sex-related behaviors due to changes in resource availability and social dynamics. Males, known to sentinel more than females in some species, might exhibit different sentinel behaviors in urban areas depending on how resource distribution and social structures change.

Maturity: Older, more experienced individuals are typically more effective sentinels. Urban environments may provide different experiences and challenges compared to natural habitats, potentially altering the relationship between maturity and sentinel behavior.

Risk: Urban environments can introduce new sources of risk, such as increased exposure to human disturbances, predators adapted to urban areas, or traffic. This heightened risk might increase the frequency or intensity of sentinel behavior as individuals remain vigilant against these new threats.

Dominance: Urban environments can influence social structures, potentially altering dominance hierarchies. Changes in dominance could affect sentinel behavior, as dominant individuals may take on more sentinel duties to protect valuable resources or maintain their status.

Group Size: Urban environments can lead to changes in group size and composition. Larger groups might have more individuals capable of performing sentinel duties, potentially reducing the individual burden of sentinel behavior but also affecting the dynamics of group coordination.

Coordination: The presence of coordination in sentinel behavior could be influenced by urbanization. Changes in group dynamics, such as altered group sizes or social structures, could affect how individuals coordinate sentinel activities.

Understanding how these factors interact in urban environments is crucial for predicting and managing the effects of urbanization on wildlife populations. Future research could focus on how urbanization alters these factors and the resulting effects on sentinel behavior, ultimately providing insights into the adaptability of animals to urban environments.

Examine the various factors associated with urban environments that may influence sentinel behavior, such as habitat alteration, noise pollution, and human presence.

Urban environments introduce several factors that can influence sentinel behavior in animals:

Habitat Alteration: Urbanization often involves significant changes to natural habitats, leading to alterations in vegetation, landscape features, and available nesting or roosting sites. These changes can impact the visibility and accessibility of potential threats, affecting the need for and effectiveness of sentinel behavior.

Noise Pollution: Urban areas are characterized by high levels of human-generated noise from traffic, construction, and other activities. This noise can mask important auditory cues, making it more difficult for animals to detect predators or communicate effectively with group members, potentially altering sentinel behavior patterns.

Human Presence: Increased human presence in urban environments can have varying effects on sentinel behavior. Some species may become habituated to human activities, leading to decreased vigilance and sentinel behavior, while others may remain vigilant due to perceived human threats or food rewards associated with humans.

Artificial Lighting: Urban areas often have high levels of artificial lighting, which can disrupt natural light-dark cycles. This disruption can affect the timing of sentinel behavior, as well as the ability of animals to detect threats or communicate visually with group members.

Pollution: Urban environments can be polluted with various substances, including chemicals, heavy metals, and plastics. Pollution can affect the health and behavior of wildlife, potentially impacting their ability to engage in sentinel behavior effectively.

Predator Presence: Some predators, such as urban-adapted species or domestic pets, may be more prevalent in urban areas. The increased risk of predation could lead to changes in sentinel behavior, with animals being more vigilant or adopting different strategies to mitigate predation risk.

Resource Availability: Urban environments often provide abundant food resources, which can influence the energy budget of animals. Increased food availability could lead to changes in satiation levels and body condition, potentially affecting the motivation and ability of animals to perform sentinel behavior.

Understanding how these factors interact and influence sentinel behavior in urban environments is important for wildlife conservation and management. Future research should focus on quantifying these effects and identifying strategies to mitigate potential negative impacts on wildlife populations.

**Implications and Future Directions:**

The findings of this review should demonstrate that sentinel behaviour is a plastic behaviour that serves primarily the sentinel, revolving generally around an individual’s need to forage (i.e. to maintain sufficient energetic reserves) and for safety. Several intrinsic and extrinsic factors can alter an individual’s propensity to perform sentinel behaviour through changes in energetic investment and requirements. An individual’s perception of its environment can then further affect an individual’s requirement for information on potential threats, thereby increasing their requirement for sentinel behaviour. Individuals can therefore modify their sentinel behaviour to best meet their personal and energetic requirements. Other group members can then alter their own behaviour to maximise the advantages provided by the sentinel, demonstrating a complex interaction between sentinel and forager. As we continue to research social behaviours, we must continue to take into consideration both intrinsic and extrinsic motivators, as we have shown that they can often interact and significantly alter behaviours. Studying the interaction between intrinsic and extrinsic factors can provide insights into the complex social dynamics and decision-making processes that behind sentinel behavior in animal groups. Further studies are required to continue analyzing this relationship and to better understand how behaviours like sentinel behaviour have evolved and become adaptive.

The effects of urban environments on sentinel behaviour require additional investigations, as human-altered environments continue to expand and affect sentinel species. How sentinel species will respond to urban living conditions must be researched. Factors such as resource availability and anthropogenic disturbances can have significant effects on social behaviours and reveal more about how individuals decide to perform sentinel behaviour. The relative lack of studies on the effects of urbanization on social behaviours, when compared to the abundance of studies on individual behaviours, represents a considerable gap in our understanding of the effects of urbanization on wildlife.

As urbanization continues globally, it is associated with a loss of biodiversity and an increase in the abundance of urbanized species. Some of these species could have adaptive behaviours such as sentinel behaviour, which in turn can contribute to the success of these species in urban environments. By further researching the effects of urbanization on social behaviours, we could infer how social species will react to urban living and help guide urban planning to better protect social species at risk.

Future research should also endeavour to create standardized protocols for testing the effects of factors such as body mass and satiation in a variety of species. These standardized protocols would permit better comparisons between species. Additionally, future research should seek additional sentinel species to determine if there are any species-specific differences in sentinel systems. Many studies focus on a limited number of species, often birds or mammals, neglecting other taxa such as reptiles, and amphibians. The study of a wider variety of sentinel species could help identify general patterns across taxa and understand the evolutionary drivers of sentinel behavior.

Our scoping review has identified several intrinsic and extrinsic factors that can significantly alter sentinel behaviour in avian and mammal species. These effects can often interact with one another, further complicating the role of internal and external influences on this social behaviour. Though the effects of urbanization on sentinel behaviour have yet to be fully understood, its potential effects on an individual’s energetic reserves and the perception of threat in its environment cannot be ignored and demand further study. Future research should focus on this source of variation in social behaviours such as sentinel behaviour. This knowledge can inform conservation efforts and urban planning to mitigate the impacts of human activities on wildlife. Ultimately, this research contributes to a deeper understanding of the intricate relationship between animals and their environments, highlighting the need for conservation strategies that consider both the individual and the ecosystem.