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REVIEW ARTICLE

Fight or flight? responses of rodents to predator cues: a review

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ABSTRACT

Rodents are common prey for a wide range of predators, including reptiles, birds, and mammals. Some of the predators (e.g., owls) depend solely on rodents for food, reducing their population significantly. Rodents respond to predators by changing behaviours to protect themselves against the enemies. Further, rodents have evolved advanced sensory capabilities that enable them to detect and effectively respond to predator cues to enhance their chances of survival. If rodents can detect their predators by chemical communication, these compounds can be extracted to repel rodents away from foods in farms and houses. However, the scientific community lacks knowledge of this phenomenon. Thus, we have reviewed the literature to get enough evidence to prove that rodents respond to predators by chemical communication. Our findings demonstrated that rodents react immediately to predatory threats by hiding or sleeping, exhibiting rapid eye movements, grouping, increased alertness, aggression, heightened anxiety, reduced activity, freezing, and avoidance. Furthermore, prolonged exposure to these cues can lead to gene changes and trigger the release of stress hormones such as corticosterone. Stress in rodents can cause hormonal imbalances, leading to decreased reproduction or smaller than normal litters. This knowledge can be used to develop alternative methods for rodent control, which can reduce reliance on poisons and promote eco-friendly and sustainable approaches to managing rodent populations. However, the majority of these ant-predatory responses have only undergone laboratory testing, providing limited field-based information. Therefore, further studies are recommended to investigate ant-predatory responses, especially those involving chemical communication, in real-world environments.

Keywords: ecologically based management, predators, predator cues, rodents, rodent responses.

INTRODUCTION

Rodents belong to Rodentia, the largest mammalian order, composing 40% of all mammals (Delaney et al., 2018). Rodents are characterized by an enlarged pair of incisors on both the upper and lower jaw that continue to grow throughout their lifetime (Cox et al., 2012). Rodents play many roles in the ecosystem both beneficial and detrimental. Beneficial roles include being useful in the laboratory as the model mammals, seed dispersal, soil improvement, pollination, and source of food for many predators including humans (Azhar et al., 2021). Nonetheless, rodents are important agricultural pests that cause significant crop losses of up to 80% and 5–12% on maize and rice crops, respectively (Mulungu et al., 2017). John (2014) reported that approximately 77 million tons of food are lost annually worldwide due to rodents. Rodents can also act as vectors of diseases to humans, such as plague and leptospirosis, through direct biting or indirect when dealing with carcasses (Mgode et al., 2014).

Rodents, being a vital part of the food chain, serve as the primary prey for numerous predators. These include snakes (Balchan et al., 2024), avian predators (e.g. owls) (Labuschagne et al., 2016), and domestic cats in human settlements (Mahlaba et al., 2017). Avian predators (e.g. owls) depend on rodents as their main food with reports indicating that about 99% of their diet consists of rodents (Saufi et al., 2020). Although owls hunt rodents, rodents have developed several mechanisms to ensure their survival and avoid their extinction which could have been brought down due to the high dependence of the predators on rodents as their source of food. One of them is the high development of senses including hearing, smelling, and vision (Delaney et al., 2018), for detecting the predator's cues. Predator cues are signals or indicators that potential prey use to detect the presence of predators in the vicinity.

The paradigm of Ecologically Based Rodent Management, which has gained momentum over the last 20 years, has led to a significant increase in studies on rodents-predators interaction, with emphasis on rodents' responses to predator cues (Swanepoel et al., 2017). Although many research studies have been conducted on rodents' response to predator cues, the existing literature is still fragmented, with each study typically focusing on specific predator-prey interactions or single types of predator cues. To our best knowledge at the current time, there is no systematic literature review done to address the variability of rodent species' responses to different types of predator cues, such as olfactory, auditory, and visual signals, and how environmental factors like habitat type influence these behaviours. As a result, a comprehensive understanding of rodents' responses to predator cues remains elusive. This review aims to fill this gap by synthesizing and harmonizing current research on rodents' immediate and long-term responses to various predator cues and exploring species-specific differences and environmental influences. By integrating findings across different studies, this review will contribute to a more comprehensive understanding of rodents on rodent-predator interactions, with implications for pest management, and conservation while also identifying key areas for future study.

METHODOLOGY

A systematic literature search by following the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) guidelines, as shown in Figure 1. The PRISMA method was used because it provides checklists of important items to be covered thus ensuring sufficient coverage of the literature The review utilized two databases: PubMed, known for its extensive collection of freely accessible articles (Ossom Williamson & Minter, 2019), and the World of Science, chosen for its broad coverage of over 44 science databases (Remy, 2009). The search used the string "Response of rodents to predators' cues" and was limited to English-language publications from 2010 to 2024. A total of 329 publications were identified: 225 from World of Science and 104 from PubMed. Duplicates, review papers, and irrelevant articles were removed and 47 articles were included.

Publications over the years

The number of publications was observed to vary from year to year from 2010 to date (Figure 2). The peak publication years of articles included in the study were 2020 and 2022 constituting of a total of 19% of all articles. In contrast, 2024 gave the least number of publications contributing to 0% of publications used in the study. The variation in publications over the years may be due to fluctuations in research activities, funding availability, or shifts in academic focus during the observed period.

Response of rodents to predators' cues.

As illustrated in Table 1 and Figure 3, 17 observed responses of rodents to predator cues. These responses can be either immediate (e. g. flight, freeze, and fight) or long-term (e.g. Epigenetic modification). Avoidance behaviour is found to be the most reported approach by diverse species of rodents in response to predators' cues. This suggests that avoidance is a widely used response of rodents when perceiving the predators' cues. In contrast, responses such as hibernation and REM sleep are reported less indicating that these responses may be utilized by a limited range of rodent species.

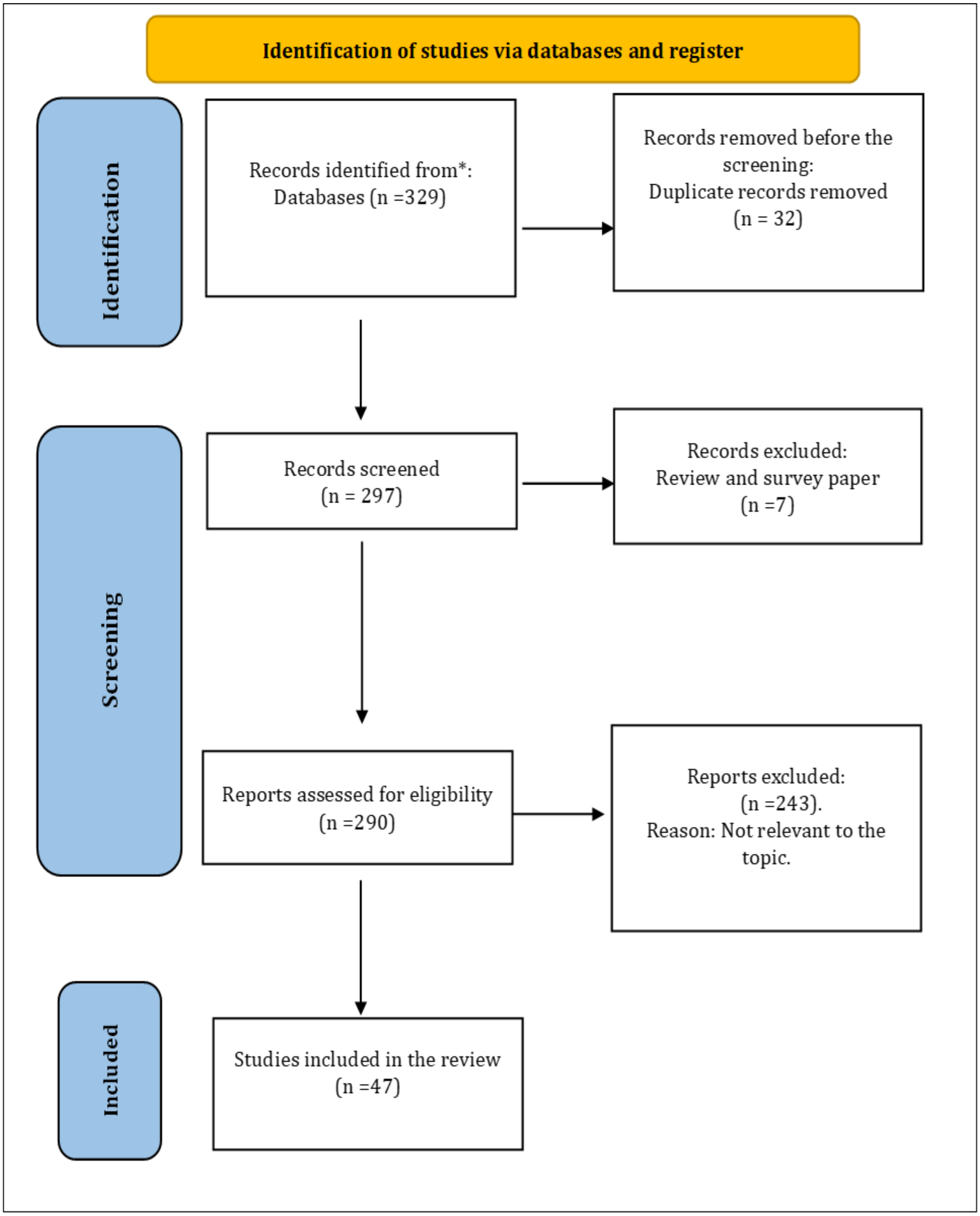

Figure 1. Representation of literature search based on the PRISMA flow diagram.

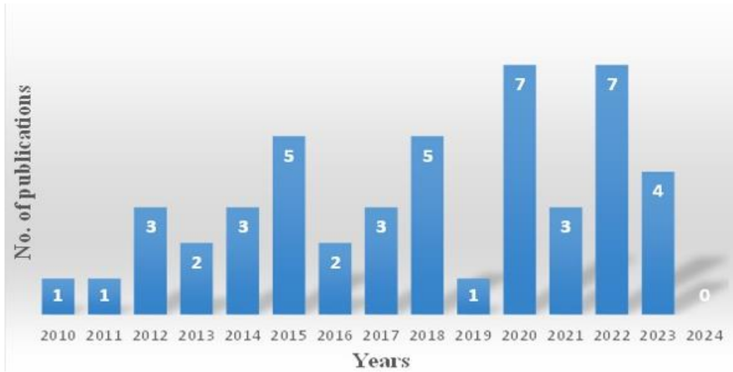

Figure 2. Distribution of publication from 2010 – 2024.

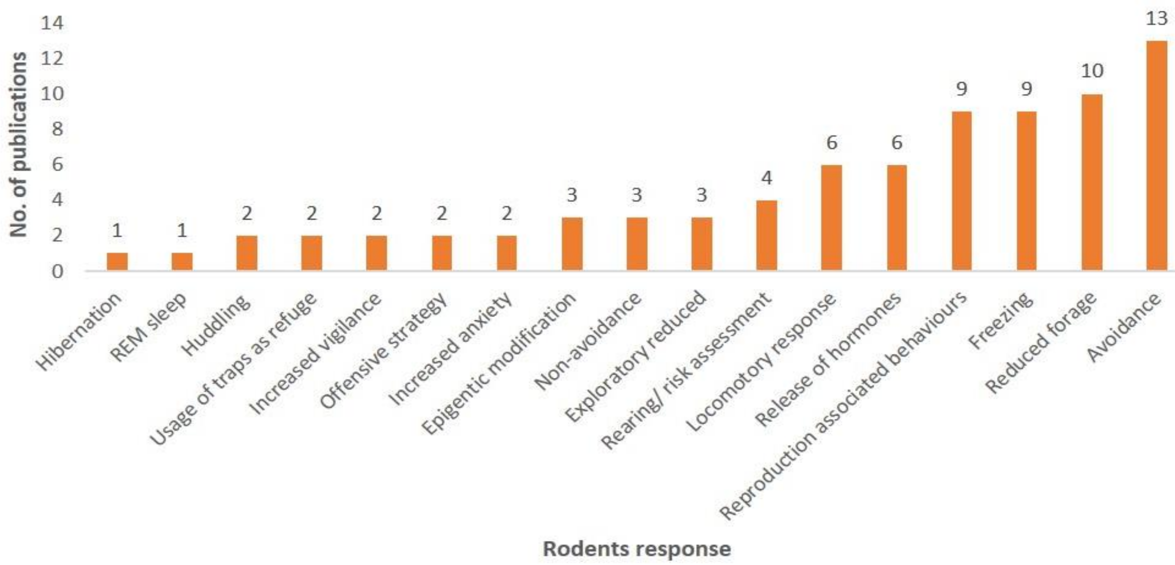

Figure 3. Rodents' Response to predators' cues as viewed in different publications.

Immediate Responses

These are responses that are likely to occur immediately after encountering predator cues. Such responses are more prevalent in rodent species compared to long-term responses. Edut and Eilam (2004) recognized fight, flight, and freezing as the major immediate responses of the rodents to the predators. However, our study found that various other immediate responses have also been reported in different research studies, in addition to the mentioned three as shown in Table 1.

Huddling

Huddling, or the aggregation of individuals within a species, is a commonly employed defensive strategy among prey. Bowen et al. (2012) experimented to observe the reactions of rodents to the presence of predator cues, specifically the odor of cat fur. The study found that rodents responded by increasing their social proximity and engaging in huddling behavior. This behavior enhances their collective defensive capabilities and significantly improves their chances of survival compared to when they remain isolated. Another study conducted by Wright et al. (2012) found that not only do rodents huddle together, but this huddling is also associated with freezing behavior. This combination offers significant advantages to the rodents: it makes them more difficult to be spotted by predators, and even if they are detected, their gregarious formation provides a better chance to outcompete predators compared to when rodents are in solitary.

Usage of traps as a refuge

Live trapping is a widely used method in ecological studies of rodents. However, it can disrupt the natural ecology. This is because some rodents, as prey, can use live traps (e.g. Sherman traps) as shelters to escape predators. A study by Hernández et al. (2018) found that in areas with live traps and increased predator risk, rodents may view the traps as safe havens. The study suggests that the benefits of being trapped, such as protection from predators, outweigh the risks associated with the traps. Thus, rodents may intentionally seek out traps to avoid predation. Another study by Hernández et al. (2021) had similar findings. It reported that in areas with increased predation, the capture rate of the long-tailed pygmy rice rat (*Oligoryzomys longicaudatus*) in live traps increased. The rodents seemed to perceive the traps as shelters when exposed to predator cues because the benefits of finding a safe shelter outweighed the risks of exploring the traps.

Non-avoidance

Not all rodents respond to predator cues by avoiding behaviours. Some species exhibit non-avoidance behaviours when they detect predator cues but fail to recognize if the cue is from a predator, especially in the case of alien predators. According to Carthey et al. (2017), rodents only exhibit avoidance behaviour when they can detect and differentiate predator cues and identify specific predators. When rodents fail to recognize and identify predator cues, they may not exhibit avoidance behaviour even when predators are present. Spencer et al. (2014) found that the spinifex hopping mouse (*Notomys alexis*) did not avoid predators despite detecting their presence, instead continuing activities such as foraging. This behaviour is also attributed to the open, spacious environment of the desert, allowing the rodents to flee quickly when predators are near. Stryjek et al. (2018) reported that certain rodent species, such as Rattus rattus, do not exhibit non-avoidance behaviour toward predators near their colonies or territories, feeling safe near their burrows or shelters as they can quickly run and hide to avoid predatory attacks.

Vigilance

According to van Schie et al. (2021), vigilance is defined as "the capability to be sensitive to potential changes in one's environment, that is the capability to reach a level of alertness above a threshold for a certain time rather than the state of alertness itself". The level of alertness in rodents due to predator cues increases to successfully avoid the predators' attack. Hernández et al. (2021) conducted field experiments showing that wild rodent species increase vigilance and become more active in response to owl calls, with their vigilance levels influenced by environmental factors like vegetation and moonlight. Bare land and high moonlight intensity further heightened their vigilance. Similarly, Jayne et al. (2015) found that Eastern grey squirrels (*Sciurus carolinensis*) exhibit heightened vigilance and disrupted foraging behaviour when exposed to predator calls, taking longer to resume normal activities.

Locomotory response

Rodents exhibit various locomotory responses to predator cues, which are critical for their survival. These responses are influenced by factors such as the predator type, the cue's nature, and environmental conditions. The study by Hernández et al. (2021) found that Abrothrix spp. tend to move slowly when moonlight is of medium intensity and predator populations are high, likely to avoid detection. In these situations, the rodents prioritize safety over foraging activities. Similar results were found by Brachetta et al. (2015), on *Ctenomys talarum* and Brachetta et al. (2018) on Tuco-tuco rodents, whereby the rodents were reported to have reduced locomotor activities to enhance their survival chance which is similar to other reviewed studies.

Although some rodent species respond to predator cues by reducing their locomotion, others increase their locomotory activities in a behavior known as flight or fleeing. *Hernandez et al.* (2021) reported that *Abrothrix spp*. exhibit fast movements (fleeing) under high-intensity moonlight, demonstrating a distinct anti-predator response. Similarly, results from studies of Hernandez et al. (2021), Yang et al. (2020), Hernandez et al. (2021), Cohen et al. (2023), and de Oliveira Crisanto et al. (2015) on the response of rodent species such as *Oligoryzomys longicaudatus*, *Rattus rattus*, and Long-Tailed Pygmy Rice Rats to cues of predators such as foxes, snakes, cats, and owls, where the bipedalism of the rodents enhances their ability to flee quickly.

Offensive strategy.

Some rodents may recognize predator cues but still exhibit non-avoidance behaviors. Tissier et al. (2019) reported that European Hamsters (*Cricetus cricetus*) employ anti-predator strategies, such as mobbing, when predator cues are detected. Mobbing involves grouping, alerting others, and collectively attacking predators, which may even lead to the predator's death. This behaviour occurs when avoidance strategies like fleeing or freezing are not viable options. Additionally, Tissier et al. (2019) noted that rodents may use other offensive strategies, such as grunting to emit sounds to chase away predators and spitting fluids to deter threats. Matsukawa et al. (2022) studied the role of the endocrine system in rodent aggression and found that stress hormones can influence aggressive behaviours, potentially making rodents more likely to attack or defend against predators.

Increased anxiety

Steimer (2011) defines anxiety as a "psychological, physiological, and behavioural state induced in animals and humans by a threat to well-being or survival." Rodents often display anxiety symptoms when exposed to predator cues perceived as survival threats. St-Cyr et al. (2017) found that male rodents exhibit increased anxiety-like behaviours, such as heightened defecation, when exposed to predator odours. Similarly, Brachetta et al. (2018) reported that rodents exposed to predator cues showed increased anxiety, characterized by reduced locomotor activity and avoidance of open spaces.

Reduced exploratory

Rodents are known to explore new areas near their habitat to secure resources (Thompson et al., 2018). However, when they detect predator cues, they often prioritize safety, reducing their exploration of unfamiliar territories. Maestas-Olguin et al. (2021) found that exposure to Coyote urine induces fear in rodents, leading to decreased exploration of unfamiliar areas, especially among younger rodents, who spend more time in a freezing state rather than exploring. This report aligns with the reports of Wright et al. (2012) and Govic and Paolini (2015) who observed similar responses in adolescent and adult rodents to predator cues.

Increased risk assessment

In some rodents, rather than reducing exploration, they increase it to assess the presence and threat level of predators. These rodents engage in heightened risk assessment by moving toward the source of the cue to gather more information (Sharma et al., 2014; Bowen et al., 2012; Maestas-Olguin et al., 2021). Govic and Paolini (2015) found similar results, showing that rodents increased exploratory behaviour such as rearing, flat-back approach, and flat-back attention after exposure to predator cues, such as cat urine. Rearing involves the rodent standing on its hind legs to enhance its view and better assess potential threats. In the flat-back approach, the rodent flattens its body close to the ground, making itself less visible and presenting a smaller target to predators. While in this posture, the rodent engages in vigilant scanning, a behaviour known as flat-back attention, to gather information about predators' presence and location.

Release of hormones

Upon perceiving predator cues, rodents' endocrine systems secrete hormones that impact their behavioural responses. Brachetta et al. (2020) found that Tuco tuco (Ctenomys talarum) rodents exposed to predator fur odours showed increased plasma cortisol levels, which were linked to anxiety-like behaviours. Wright et al. (2012) observed that both adolescent and adult rodents had elevated corticosterone (CORT) levels after exposure to predator cues, with adolescents retaining higher levels for longer periods and females secreting more CORT than males. Similar increases in CORT were noted by Sotnikov et al. (2011) in response to predator cues.

Hernández et al. (2021) found that Long-Tailed Pygmy Rice Rats exposed to Culpeo Fox showed increased glucocorticoid levels, which led to the mobilization of food reserves from non-vital organs to provide energy for rapid responses to threats. Voznessenskaya (2014) also reported elevated corticosterone levels in *Mus musculus* exposed to cat odour. Additionally, St-*Cyr et al.* (2017) found increased levels of both CORT and Adrenocorticotropic hormone (ACTH) in rodents exposed to predator cues, with ACTH helping regulate CORT production during stress. The increased levels of stress hormones may induce immediate avoidance behaviours such as restricted growth while chronic exposure has been linked to a reduction in litter sizes (Adduci et al., 2021).

Freezing

Freezing is defined as the absence of movement except for respiratory actions (Maestas-Olguin et al., 2021; Wright et al., 2012). It is a common fear response in animals like rodents, who freeze in place, crouching to blend into their environment and avoid predators (Solomon, 2016). Numerous studies have reported increased freezing behaviour in rodents upon detecting predator cues. Yang et al. (2020) found that mice exposed to predator cues exhibited prolonged freezing, consistent with findings by Maestas-Olguin et al. (2021), Wang et al. (2013), Sharma et al. (2014), Matsukawa et al. (2022), and de Oliveira Crisanto et al. (2015). Cruz et al. (2020) showed that rodents can learn from previous threats and recognize freezing in other rats as a danger signal. The freezing behaviour varies with the age and sex of the rodents. Wright et al. (2012) observed that adolescents freeze more than adults, indicating higher sensitivity. Liu et al. (2022) found that male rodents freeze more than females, who spend less time freezing before resuming exploration. Figure 4 shows the freezing behaviour under cruising predators (A) and the change of behaviour from freezing to flight after approaching predators (B).

Reduced foraging

Rodent foraging is the behavior and activities of rodents for searching for and gathering food. This behavior is crucial for their survival, influencing their diet, habitat preference, and social interactions. Foraging animals are at risk of predation while searching for, processing, and consuming food. So, the presence of predators in the rodents' habitat has been reported by numerous studies to reduce the foraging behaviour of rodents. For example, Bowen et al. (2012) found that rodents avoid foraging when exposed to cat odour, a finding supported by Hernández et al. (2021) on *Rattus rattus* and *Abrothrix spp* with owl calls, Tissier et al. (2019) on European hamsters with cat urine, Mahlaba et al. (2017) on Rattus rattus and Mastomys natalensis with domestic cats and dogs, and Villalobos et al. (2022) on bank voles with red fox feces, Bleicher et al. (2020) on rodents with ninja owls, Bleicher et al. (2018) on bank voles with least weasels and Kovacs et al. (2012) on *Rattus fuscipes* and *Antechinus stuartii* with alien predators such as *Vulpes vulpes*.

Taylor *et al*. (2023) and Farnworth et al. (2016) extended the understanding of prey-predator interactions by highlighting the role of environmental factors such as moonlight illumination on rodent foraging behaviour. They found that during brighter nights, small mammals reduced their foraging activities due to the increased risk of predation, which outweighed any advantages of better visibility. Randler and Kalb (2020) found that if rodents detect a food source before predators, they prioritize feeding over safety to capitalize on the available resources. Conversely, if predators first locate the food source, rodents shift their focus to avoid predation. This shows that rodents' foraging strategies are very flexible and depend on their surroundings and whether predators are nearby.

Avoidance

Avoidance is the most reported rodent response to predator cues in reviewed publications. López-Moraga et al. (2022), defined avoidance as the response that increases the distance between the individual (rodents) and the threat (Predator). The reduction of contact between the rodents and the predators reduces their chances of encountering threats thus increasing their survival chances. For instance, the results from the study by Tissier et al. (2019) on European hamsters and Zhigarev et al. (2023) on bank voles in Y-maze tests found that the rodents avoided going to the branch with cues showing that the rodents' sense and avoid proximity to predators' cues.

Numerous studies have consistently demonstrated that rodents exhibit avoidance behaviors when encountering predator cues. Maestas-Olguin et al. (2021) and Wright et al. (2012) observed a reduction in rodent proximity to coyote and cat urine, respectively. Additionally, Govic and Paolini (2015) confirmed the avoidance behavior in response to predator cues. St-Cyr et al. (2017) reported that both male and female adult rats demonstrated avoidance of bobcat and coyote urine, with male offspring exhibiting higher avoidance behavior. Furthermore, Dickman et al. (2022) demonstrated that rodents recognized and avoided sand goanna odor, while Zhigarev et al. (2023) and Matsukawa et al. (2022) noted avoidance responses in bank voles to predator-derived odors. Moreover, Apfelbach et al. (2015) found that dwarf hamsters exhibited avoidance behavior in response to European ferrets, and Brachetta et al. (2020) observed avoidance in Tuco tucos in response to predator odors. Finally, Randler and Kalb (2020) reported that rodent species, including *Glis glis*, avoided areas where martens fed. These collective findings underscore a consistent pattern of avoidance behavior in rodents in the presence of predator cues.

Other studies went a step further in assessing the environment's effect on rodents' response to the predators' cues. It was found that environmental conditions such as illumination, increase the avoidance behavior of the rodents to avoid being spotted by predators. This is evidenced by the studies done by Bowen et al. (2012), on the response of rodents to cat odour in bright light, and Farnworth et al. (2016) on the effect of light on the foraging behaviour in the presence of rodents where it was found that the rodents moved away from the bright light to decrease their chances of being detected.

Long-term Responses

Long-term responses (Table 1) are adaptations or changes in behaviour, physiology, or development that occur over an extended period due to prolonged exposure to threat. Unlike immediate responses, which are quick and short-lived, long-term responses develop gradually and can have lasting effects on an organism. These responses are often aimed at improving survival and reproductive success in the face of sustained threats.

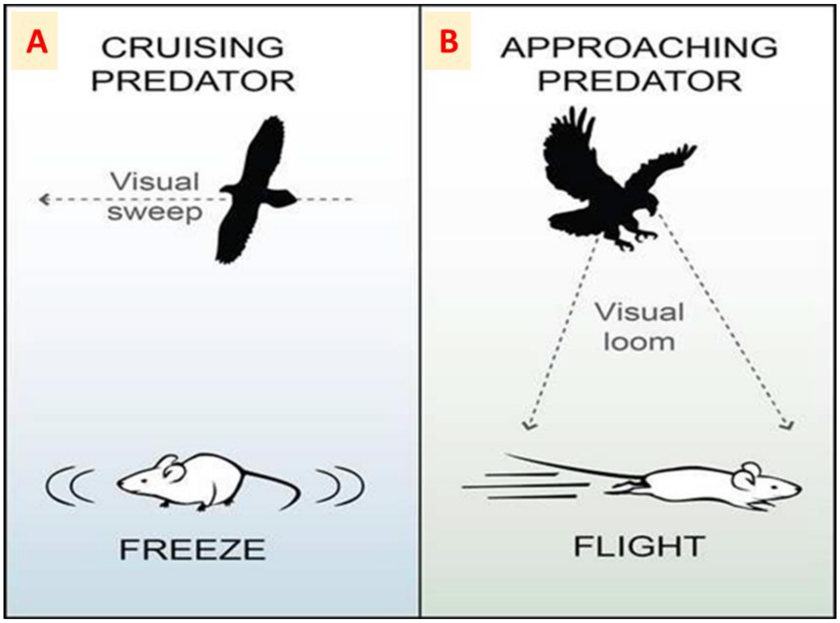

Figure 4. (A), Shows the freezing behavior under cruising predators. (B), showing the change of behaviour from freezing to flight after approaching predators.

Table 1. Summary of rodents' responses to predators' cues as reported in the reviewed papers

Sl. No.	Duration of Response	Response	References
1.	Immediate	Huddling.	Bowen et al. (2012); Wright et al. (2012)
		Usage of traps as a refuge.	Hernández et al. (2018); Hernández et al. (2021).
		Non-avoidance.	Spencer et al. (2014); Carthey et al. (2017); Stryjek et al. (2018).
		Vigilance.	Jayne et al. (2015); Hernández et al. (2021).
		Locomotory response.	Brachetta et al. (2015); de Oliveira Crisanto et al. (2015);Brachetta et al. (2018); Yang et al. (2020); Hernández et al. (2021); Cohen et al. (2023).
		Offensive strategy	Tissier et al. (2019); Matsukawa et al. (2022)
		Increased anxiety.	St-Cyr et al. (2017); Brachetta et al. (2018)
		Reduced exploratory.	Wright et al. (2012); Govic and Paolini (2015); Maestas-Olguin et al. (2021).
		Increased risk assessment.	Sharma et al., (2014); Bowen et al., (2012); Govic and Paolini (2015); Maestas-Olguin et al., (2021).
		Freezing	Wang et al. (2013); Wright et al. (2012); Sharma et al., (2014); Yang et al., (2020); Cruz et al. (2020); de Oliveira Crisanto et al. (2015); Liu et al. (2022); Maestas-Olguin et al. (2021); Matsukawa et al. (2022);
		Reduced foraging.	Bowen et al. (2012); Kovacs et al. (2012); Farnworth et al. (2016); Mahlaba et al. (2017); Bleicher et al. (2018); Tissier et al., (2019); Randler and Kalb (2020); Hernández, et al. (2021); Taylor et al. (2023); Villalobos et al. (2022).
		Avoidance.	Bowen et al. (2012); Wright et al. (2012); Apfelbach et al. (2015); Govic and Paolini (2015); St-Cyr et al. (2017); Brachetta et al. (2020); Dickman et al. (2022); Farnworth et al. (2016); Tissier et al. (2019); Randler and Kalb (2020);

			Maestas-Olguin et al. (2021); Matsukawa et al. (2022); Zhigarev et al. (2023).
		Reduction of sleep	Aime and Adamantidis (2022)
2.	Long-term	Hibernation	Ruf and Bieber (2023)
		Epigenetic modification.	St-Cyr et al. (2017); Brass et al. (2020); Wu et al. (2022).
		Reproduction-associated behaviors.	Sukikara et al. (2010); Bowen et al. (2012); Starke et al. (2013); Voznessenskaya (2014); Ayers et al. (2016); St-Cyr et al. (2017); Haapakoski et al. (2018); Wu et al. (2020); Karigo and Deutsch (2022).
		Release of hormones	Sotnikov et al. (2011); Wright et al. (2012); Brachetta et al. (2020); Hernández et al. (2021)

Hibernation

Hibernation is an extended period of reduced metabolic activity. According to Ruf and Bieber (2023), rodents such as the edible dormouse enter hibernation in response to predator cues rather than poor environmental conditions. During hibernation, dormice retreat into underground burrows with fat reserves as food source, at the expense of reduced reproduction. Once their habitat is safe again, they emerge and increase mating to compensate for lost reproduction, thus recolonizing their habitat.

Reduction of Sleep

Rodents are highly vulnerable during sleep, which makes this period critical for potential predation. According to Aime and Adamantidis (2022), in the presence of stress or predator cues, rodents significantly change their sleeping patterns by reducing both rapid eye movement (REM) and non-rapid eye movement (NREM) sleep. In other words, when rodents are exposed to predator cues, they decrease their total sleep time. This reduction effectively decreases the period during which rodents are susceptible to predation, allowing them to remain more active and ready to flee if threatened. Additionally, Aime and Adamantidis (2022) reported that rodents reduce the length of individual REM sleep episodes in response to predator cues. This adaptive behaviour results in more frequent awakenings, enhancing the rodents' vigilance and preparing them to immediately fight or flee when a predator is present. This heightened alertness is essential for their survival in environments with constant predator threats.

Epigenetic modification

Rodents don't always respond to predators' cues solely for self-protection; sometimes, they enhance the adaptive capabilities of their offspring. Brass et al. (2020) found that rodents alter their parental epigenome in response to stress imposed by predator cues, which can be passed on to their offspring. Offspring of parents exposed to predator cues became more active and less anxious, suggesting that parental exposure to predator cues leads to altered germlines in offspring, making them better adapted to environments with high predator presence. Similar findings were reported by St-Cyr et al. (2017) whereby the parents exposed to predator cues were able to transmit the modified epigenome to the offspring, altering the way the offspring could normally respond to the predator cues and becoming better adapted than their parents. Wu et al. (2022) supported previous findings, indicating that when mother animals are exposed to predators postpartum, it influences how their offspring react to threats later in life. The adult offspring tend to exhibit passive-avoidant behaviour in response to predator cues, thereby showing a cross-generational maternal effect.

Reproduction-associated behaviors

Reproduction is one of the vital factors that affect the population of rodents. However, the presence of the predators is reported to affect the reproduction of the rodents either by triggering reproduction or causing cessation of reproduction. Several studies suggest that exposure of rodents to predators' cues reduces both reproduction capabilities and maternal behaviours. Bowen et al. (2012) found that rodents exposed to predators' cues experienced reduced reproduction. Similarly, Karigo and Deutsch (2022) observed that male mice behaviours were affected by predators' cues, diminishing mating behaviour and overall reproduction. Voznessenskaya (2014) reported that Mus musculus responded to cat odour by blocking pregnancy up from 31.25% to 68.75% (Bruce effect) potentially induced by associated corticosterone levels. On the side of the effect of predators' cues on maternal behaviours, Wu et al. (2020) found that exposure to predators' cues disrupted maternal care in female rodents such as licking the offspring. Also, Sukikara et al. (2010) observed the expressed defensive behaviours in the expense of inhibition of maternal behaviours

Some studies suggest that exposure to predator cues can trigger reproductive abilities and maternal care in certain rodent species, contrasting with earlier reports of decreased reproductive potential. Haapakoski et al. (2018) found that exposure to predator cues increased litter size by up to 50% in wild rodents to ensure colony survival. Ayers et al. (2016) observed enhanced maternal behaviors, such as nurturing and grooming, to protect offspring from predators. However, other studies, like Starke et al. (2013) on house rodents (Mus musculus) and St-Cyr et al. (2017) on Long-Evans rats, found no significant impact on reproduction or maternal behaviors following exposure to predator cues.

CONCLUSION

Rodents are highly successful organisms, largely due to their adaptive behaviours and physiological responses to predators. They exhibit a range of defensive behaviours, such as avoidance, huddling, mob attacks, and freezing, in response to various predator cues, including auditory signals (predator calls), visual cues, and olfactory markers (fur, urine, and feces odours). These strategies enhance their survival by helping them avoid predators, contributing to the overall success of rodent species in their environments. The rodents' natural tendency to avoid predator cues can be leveraged as a strategy for rodent management. By using products that mimic these cues, it is possible to repel rodents from unwanted areas like homes and farms. This method represents a promising alternative to synthetic pesticides, which are known to have harmful environmental effects. The use of predator cues is an ecologically based management approach that could significantly reduce the need for chemical control methods. In Tanzania, efforts are already underway to develop such biological controls. Mulungu et al. (2017) have shown that female cat urine odour can effectively repel commensal and field rodents, with the potential for commercialization as a rodent management tool. This shows that the use of predators' cues is the future of rodent management and more efforts should be allocated to researching the use of Predators' cues in rodent management in Tanzania. However, while the findings from the review are promising, it is crucial to acknowledge the limitations of the current body of research. Most studies to date have been conducted within the laboratory environments. The natural ecosystem, with its inherent complexity and variability, poses a far greater challenge. Consequently, field studies often yield more variable and less predictable results. To bridge this gap, it is important to integrate field studies alongside laboratory research. This combined approach would provide a more comprehensive understanding of how rodents respond to predator cues in real-world settings.

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AUTHORS CONTRIBUTION STATEMENT

Conceptualization: Martin, M. J; Literature search and selection: Mulungu, E. L; Data extraction and synthesis: Mulungu, E. L; Writing - Original Draft: Mulungu, E. L; Writing - Review & Editing: Martin, M. J.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

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