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The impact of perceived safety on Sciuridae foraging behavior in the northern Sierra Nevada

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ABSTRACT

All organisms consider the tradeoffs of cost and benefit of their actions. Foraging Sciuridae incorporate this dynamic when deciding how and where to forage. By observing food acquisition behaviors in forested and open environments, we studied how Sciuridae at the Sagehen Creek Field Station consider these risks and rewards at safe and unsafe locations while foraging. Sciuridae's foraging behavior, mainly feeding and collecting, were proxies for us to determine the level of threat that Sciuridae's perceived to be in safe and unsafe sites. We timed the duration of each behavior in both locations through camera trap footage and accounted for the frequency of each behavior in both safe and unsafe sites. Sciuridae generally spent more time in safe areas regardless of the action. Within safe areas feeding was most often performed, and collecting was most often performed in unsafe areas. Preferences for safe areas could be attempts by Sciuridae to avoid predation threats; however, social factors could also further shape their foraging behaviors.

Keywords: Sciuridae, foraging behavior, trade-offs

INTRODUCTION

The diversity of organisms throughout the planet can be attributed to their unique methods of survival, which result from the consideration of tradeoffs (Tilman 2000). Tradeoffs occur when receiving a benefit requires accepting an associated cost or risk, and foraging is defined as the search for wild food resources necessary for subsistence. To study the relationship between tradeoffs and foraging behaviors, scientists measure the maximum yield that animals can gain from an activity. The balancing of risks and rewards through tradeoffs informs how organisms behave.

Examples of tradeoffs across species can be found from apex predators to autotrophs. A research team led by Justine Smith found mountain lions (*Puma concolor*) adapting their feeding behavior to avoid encounters with humans. The research findings proved the cats shortened their feeding time of deer prey to avoid perceived danger from humans at the risk of losing high-caloric-value food. In response to the perceived danger of humans, mountain lions instead consume lower-calorie food that takes less time to eat, demonstrating the tradeoff between consuming quality food and threats of predation (Smith et al. 2017). Vicuñas (*Vicugna vicugna*) in a 2019 study were

observed grazing in meadows that are cohabited by predators. These meadows offer a source of food for vicuñas in resource-limited areas. Although they face the strong threat of predation by mountain lions in this habitat, vicuñas continue grazing the lands and opting to use dynamic behaviors such as avoiding these meadows during active times of predation from the mountain lions (Smith et al. 2019). Similar and distinct patterns in other species that follow these principles of tradeoff dictate all organisms' behaviors.

Small mammals utilize tradeoffs to optimize foraging efforts. A common tradeoff between competitive ability and defense against predators is to allocate resources to defense while reducing resources for competition, creating ecological and evolutionary consequences (Jessup and Bohannan 2008). Sciuridae foraging behavior reflects this notion of tradeoff predisposition as they choose how to go about foraging while accounting for the risk of predation and competition in their environment. While predation directly threatens safety and their ability to survive, competition threatens the ability to access resources. Their reward while foraging is gaining high-quality food to meet their current caloric needs. Foraging is made up of feeding and collecting (Delgado et al. 2014). Feeding requires more attention to the action, but this attention can be diverted towards competitors and predators (Teichroeb et al. 2024). Collection does not involve eating the food at the location of discovery instead storing it in their mouths for later retrieval. Collection then cuts down the time at the site, allowing for the Sciuridae to choose a safer location to eat their food (Lima 1985).

The behavior of Sciuridae is informed by assessments of the abiotic habitat, predator, and competition. Sciuridae must decide how to forage in variable terrain with high predation by choosing how much time to dedicate to an action that might require more attention and where to feed or collect. This study examines how foraging behavior reflects the tradeoffs between perceived predation in safe and unsafe physical locations (Clermont et al. 2017). We expect Sciuridae to be spotted more often in safe areas except for yellow-pine, which will be more frequent in unsafe areas. Eating will occur more frequently and for longer stretches of time in safe microhabitats compared to unsafe ones (Carey and Moore 1986). Conversely, we hypothesize Sciuridae spend less time in unsafe microhabitats, with most of the time spent there allocated to collecting.

METHODS

2.1 Study Site

Our study was conducted at Sagehen Creek Field Station (39.432056°N, 120.241348°W) located in Truckee, California from July 30, 2026 to August 2, 2026. The species we studied at Sagehen Creek Field Station were two species of squirrels, the chickaree (*Tamiasciurus douglasii*) and golden-mantled ground squirrel (*Callospermophilus lateralis*). We also studied three species of chipmunks which were the yellow-pine chipmunk (*Neotamias amoenus*), lodgepole chipmunk (*N. speciosus*), and long-eared chipmunk (*N. quadrimaculatus*). During the summer season, Sagehen Creek Field Station is averages 26 °C during the day but can reach lows of 3 °C (UCNRS 2004). During this time chipmunks are having their latest litter of

pups in mid-June (Verts and Carraway 2001). For chipmunks it takes a short amount of days to be able to stand and develop their incisors which can take about 27 days after their birth (Verts and Carraway 2001). Squirrels are making their first appearances with their pups in late June and July which is when their pups have finished weaning and are ready to go above ground (Wells and Van Vuren 2018). The food supplied for chipmunks and squirrels in early summer comes in small quantities when it comes to the first fruits and there is an abundance of green vegetation (Storer et al. 1944). During late summer there are plenty of fruits available as well as a great number of grasses (Storer et al. 1944). The consumption of food during this season is composed of mainly fungi, seeds, and arthropods across Sciuridae (Tevis 1953).

The five different species of Sciuridae we studied have different spatial preferences. Chickarees are seen in a variety of places reaching from southwestern British Columbia, western Washington and Oregon, northern California and the Sierra Nevada (Carey 1991). Chickarees live in coniferous forests and fir, spruce, and hemlock forests (Ingles 1990). The golden-mantled ground squirrel resides in pine and fir forests ranging from Oregon, eastern Washington, and northern California (Ingles 1990). Yellow-pine chipmunks live in open forests in Oregon, northern California, eastern Sierra south to Mono County, and montane and subalpine zones of Washington (Ingles 1990). Lodgepole chipmunks reside in subalpine, red fir, and lodgepole forests located in central and northern Sierra Nevada, San Bernardino, San Gabriel, Ventura County and subalpine and montane zones of California (Ingles 1990). Long-eared chipmunks are seen in open, brushy, and rocky places in yellow pine and Douglas fir forests in the Sierra Nevada (Ingles 1990).

For each individual species in the Sciuridae family that we studied, we used their range preferences to reflect if we would observe them in what we considered safe or unsafe. chickarees, golden-mantled ground squirrels, and lodgepole chipmunks reside in safe areas based on their ranges. Long-eared and yellow-pine chipmunks reside in unsafe areas based on these descriptions.

2.2 Camera Trap Study

In our camera study we placed cameras depending on two different habitat types: safe and unsafe. Safe habitats were classified as having montane trees within a five-meter radius. There had to be five mature trees within this five-meter radius. In addition to the montane trees there also had to be grass that covered the five-meter radius and 25% of the area was shrub cover. Unsafe habitats had no tree canopy cover, and the closest trunk was at least ten meters away from the center of our study area. The rocks had to cover the entire area, which means that from the center of the rocky area there had to be a radius of five meters for it to be considered rocky. We measured these variables during our pilot data collection and used a range finder to give us all our distances. For this study we target sampled as well, so we chose an area for our study and went 50 m away from the previous area to find our new location.

We identified a total of 14 safe and 14 unsafe sites, and we had a total of 28 cameras which were divided evenly between both sites. For the first and second day we had five cameras on each safe and unsafe site, the third day we had four cameras on each safe and unsafe site. We rotated the

cameras to new sites every day at 2 p.m. The cameras were picked up again at two in the afternoon the next day making them set out for roughly around 24 hours. Once the cameras were set up, we placed 15 mL of an unknown brand of bird seeds mixed with shelled and kernel sunflower seeds to observe foraging. Each camera was at least 50 m from one another to avoid recording the same individuals (Kelt et al. 2013).

In our camera trap study, we focused on observing five species of Sciuridae foraging behaviors, which are feeding and collecting. Each camera trap was set to high sensitivity in order to account for any movement of these small rodents. The cameras were set to take one-minute-long videos to view foraging behaviors in more detail. There was no quiet period so that cameras recorded videos back-to-back with no issues or pauses. We differentiated the chipmunks and squirrels by species which were chickaree, golden-mantled ground squirrel, yellow-pine chipmunk, lodgepole chipmunk, and long-eared chipmunk. Using a field guide, we determined the key features of each individual to identify them by species (Laws 2007).

Once we collected the cameras, we got the SD cards and watched all the footage in the safe and unsafe areas. We recorded the total time (in seconds) it took for the five species of Sciuridae to perform either feeding or collecting behaviors. We determined feeding as them constantly eating the seeds without their cheek pouches getting full. We also would see the Sciuridae drop the seeds when they finished eating it. For collecting we would see when the different Sciuridae would stuff their internal cheek pouches and we could visually see their mouths getting fuller over the minute long video footage. In addition to the time the Sciuridae performed these behaviors we also measured how long it took for them to first come to the safe or unsafe site in minutes.

2.3 Statistical Methods

We ran a t-test to demonstrate the effects of habitat type (safe or unsafe) on the average time spent collecting within Sciuridae. We then ran another T-test to show the effects of habitat type on the average time spent feeding also within Sciuridae. Both T-tests were displayed on the same figure. We also ran a chi-squared test to show the effects that habitat type has on the proportion of time spent foraging or feeding within Sciuridae. All statistics were conducted using 2026 JMP® Version 18. JMP Statistical Discovery LLC, Cary, NC.

RESULTS

The total abundance of detections we observed was higher in unsafe areas than in safe areas (Fig. 1). In safe areas long-eared chipmunks were spotted the most, and the least spotted species was the yellow-pine chipmunk (Fig. 1). In unsafe areas yellow-pine chipmunks were the most spotted, and the least spotted was the chickaree (Fig. 1). We saw a greater average time collecting in safe areas than in unsafe areas ($N_{safe} = 56$, $N_{unsafe} = 44$, $t(74.5) = -3.45$, $p = 0.0005$; Fig. 2). We also saw a greater average collecting time in safe areas than unsafe areas ($N_{safe} = 19$, $N_{unsafe} = 54$, $t(29) = -2.39$, $p = 0.0131$; Fig. 2). We observed a higher proportion of Sciuridae exhibiting feeding behavior in safe areas than in unsafe areas and a higher proportion exhibiting collecting behavior in unsafe areas than safe areas ($N = 167$, $\chi^2(1) = 18.691$, $p < 0.001$; Fig. 3).

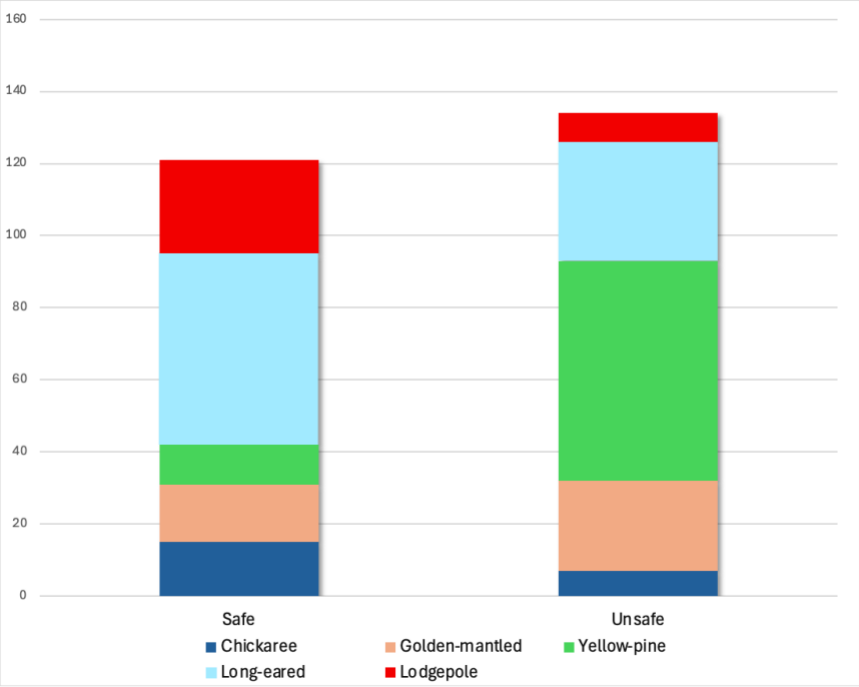


Figure 1. Total detections of Sciuridae in safe and unsafe areas by species. Camera traps were set out in forested ("Safe") and open areas ("Unsafe") and collected daily from July 30 to August 2, 2026, at Sagehen Creek Field Station in Truckee, California. Bar heights represent total detection of Sciuridae counts per habitat type, and each segment represents the absolute amount of detections per species observed (N = 255 total).

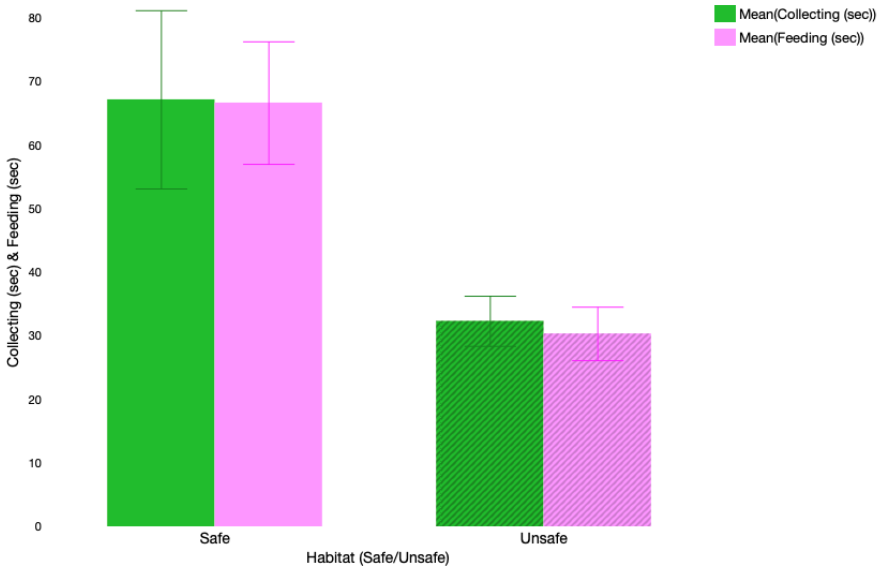


Figure 2. There were longer average collecting and feeding times in safe areas than in unsafe areas. Feeding and collecting times in Sciuridae was observed in this study using camera traps that were set out in forested ("Safe") and open areas ("Unsafe") and collected daily from July 30 to August 2, 2026, at Sagehen Creek Field Station in Truckee, California. Error bars represent one standard error from the mean. Dashed lines indicate mean collecting time and mean feeding time observed in unsafe areas. (Feeding; $N_{safe} = 56$, $N_{unsafe} = 44$, $t(74.5) = -3.45$, $p = 0.0005$). (Collecting; $N_{safe} = 19$, $N_{unsafe} = 54$, $t(29) = -2.39$, $p = 0.0131$).

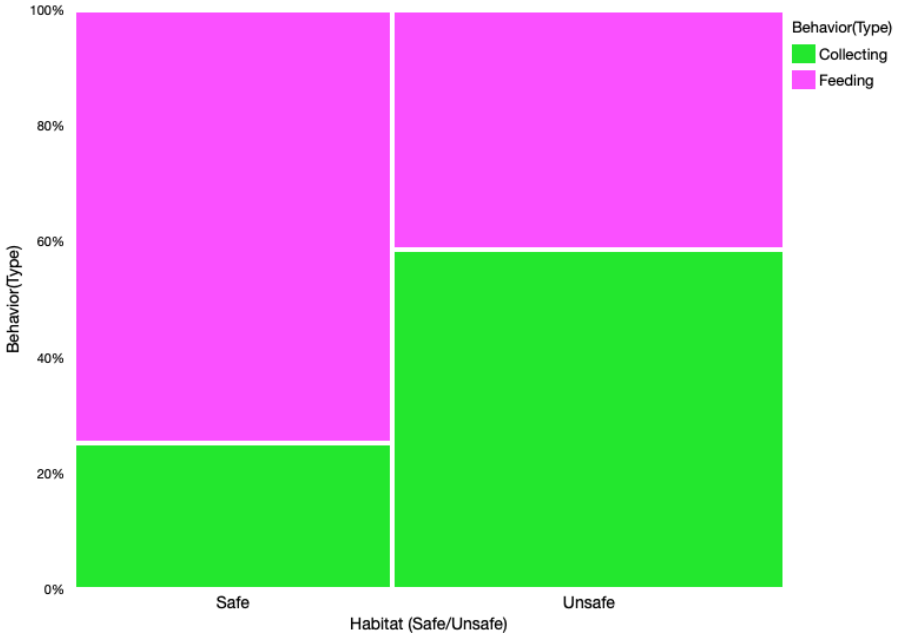


Figure 3. There was a higher proportion of Sciuridae exhibiting collecting behavior in unsafe areas than in safe areas, and there was a higher proportion of feeding behavior in safe areas than unsafe areas. The proportions of collecting and feeding behaviors of Sciuridae at Sagehen Creek Field Station in Truckee, California, were observed using camera traps placed in forested ("Safe") and open areas ("Unsafe") that were collected daily from July 30 to August 2, 2026. ($N = 167$, $\chi^2(1) = 18.691$, $p < 0.0$

DISCUSSION

The safe areas in our study, selected from locations that provided a protective tree canopy, were visited most by long-eared chipmunks, matching findings from a 2024 study that indicated that this species prefers sheltered areas (Huang et al. 2024). Unsafe areas in our study provided no canopy cover and were visited mostly by yellow-pine chipmunks, who according to this same study prefer to forage in open areas in the Sierras. The tendency of yellow-pine chipmunks to forage in open areas could also explain why they composed the smallest number of visits to safe areas. Chickarees typically forage near trees to access pinecones as a food source and had the lowest number of visits to unsafe areas, most likely because the lack of trees in these sites limits access to their preferred food source (Daw 2021). Future studies about how this variation in foraging behaviors has developed across Sciuridae species at Sagehen could provide a stronger understanding of which factors shape each species' unique foraging patterns.

Across all study subjects, the mean collecting and feeding times were highest in safe sites, with the most overall time spent in safe areas than in unsafe ones. This matches our expectation that Sciuridae are more likely to feed and be found in safe sites. A study looking at the foraging behavior of house mice in outdoor enclosures compared behaviors in enclosures with mowed and overgrown vegetation (Powell and Banks 2004). Researchers found that although the mice observed had been bred in captivity and had not previously encountered predators, they foraged more in "closed" habitats (grown vegetation) than in "open"

ones (mowed vegetation). The mice demonstrated a pattern that comes from an innate foraging behavior used to avoid predation threats (Powell and Banks 2004). Frequenting sheltered areas more than open areas was also a pattern exhibited by Sciuridae in our study and could be a behavior implemented for the similar purpose of avoiding predators. Another study found that differences in vigilant behavior in eastern chipmunks in forested and open areas indicated that chipmunks expected a higher level of predation risk in open areas and a lower one in forested areas (Clermont et al. 2017). Like the eastern chipmunks of this study, Sciuridae observed in our work could also expect a higher predation threat in open areas, and foraging more in safe areas could allow them to minimize any predation threats. Overall, spending time in safe areas could be a way for Sciuridae at the Sagehen reserve to manage both the external dangers of their environment and their feeding needs.

However, in our study foraging, feeding, and collecting were not limited to safe sites. Although the proportion of collecting behavior was highest at unsafe locations and the proportion of feeding behavior was highest in safe locations, both feeding and collecting behaviors were observed in both site types. If predation threat was the only factor shaping foraging behavior, we would expect Sciuridae to forage only within safe sites. Foraging in both safe and unsafe location types could mean that factors outside of predation also influence foraging behaviors. For example, competition for food within safe foraging sites is another risk Sciuridae must consider in their foraging decisions (Otter 1994). In eastern chipmunks, competition and territorial aggression have sometimes resulted in individual chipmunks being forced to forage in open habitats, despite the predation threat they may face. If Sciuridae at Sagehen place similar social pressures on each other through competition, then this could be a possible cause for the observed foraging in unsafe sites. In this context, Sciuridae must consider not only the threats of predation within their physical environments but the social landscapes of their habitats as well. They then must develop a trade-off between these external factors and their feeding needs. The different foraging strategies implemented by each species in our study could signify that they have different ways of managing this trade-off. Studying how social pressures in Sciuridae shape foraging patterns would provide insight into how factors such as competition, feeding needs, and predation threats interact at the Sagehen reserve and would be key in understanding how Sciuridae navigate their environments.

When making decisions about foraging, including where and how long to feed or collect, Sciuridae at Sagehen must balance external predation threats and perhaps competitive factors with their own energy needs as organisms. Some must face higher predation threats to obtain food, while others may take advantage of resources available at safer sites (Otter 1994). Our results provide some insight into how Sciuridae manage the delicate balance between outside pressures and individual needs through the tradeoffs they implement into their own foraging strategies.

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