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Assessing Anthropogenic Effects on Golden-mantled Ground Squirrel and Least Chipmunk

Flight Initiation Distances

Abstract

Species who commonly occupy territories within human settlements are exposed to frequent human disturbance, which has been linked to significant shifts in wildlife behavior in past studies. As urbanization and rural development continue to increase, we can anticipate cohabitation between humans and wildlife to also increase, creating a growing need to understand the effects of repeated human disturbance on wildlife behavior across a variety of taxa. Flight initiation distance (FID) is a common metric used to quantify antipredator behavior and boldness in wildlife populations and is used to assess perceived risk of a pursuer from the perspective of a fleerer. We conducted FID trials on golden-mantled ground squirrels (*Callospermophilus lateralis*; GMGS) and least chipmunks (*Tamias minimus*; CPMK) across 11 sites of varying levels of human disturbance to determine the effect of human disturbance on FIDs through a generalized linear mixed effects model. We found a statistically significant positive relationship between proportion of impervious surfaces within a buffer range of the animal and FID for CPMK, as well as a reliably positive effect of distance to road on FID for CPMK. GMGS had reliably positive effects of distance to road and distance to trails on FID. Starting distance was significant for CPMK and GMGS.

Introduction

As urbanization and land development continues to expand, coexistence between humans and wildlife will also increase (Li et al., 2022), creating a growing need to understand the impacts of anthropogenic processes on wildlife behavior. Past studies have indicated that increased exposure to human activity affects wildlife behaviors, such as decreased GUDs in gray squirrels, *Sciurus carolinensis* (Bowers and Breland, 1996), decreased behavioral reactivity to capture in California ground squirrels, *Otospermophilus beechyi* (Hammond et al., 2019), and even decreased mass-gain in yellow-bellied marmots, *Marmota flaviventer* (Uchida and Blumstein, 2021). Shifting patterns in wildlife behavior as a result of repeated human disturbances can impact survival outcomes, notably in regards to antipredator responses.

A common metric used to quantify antipredator behavior and individual ‘boldness’ is Flight Initiation Distance or “FID” (Blumstein et al., 2023), which is defined as the distance at which an animal flees from an approaching threat (Morelli et al., 2022). FID can be influenced by a variety of individual and environmental factors (Blumstein et al., 2023), and can vary between different species (Moller et al., 2014). Furthermore, FID can vary across populations as a result of learning and local adaptation (Moller, 2015) and between individuals within a population (Allan et al., 2014). A study in yellow-bellied marmots found that average FID decreased with repeated approaches, especially in areas with greater levels of human disturbance (Uchida and Blumstein, 2021), an example of habituation, or the decrease in a behavioral response (FID) to a repeated stimulus (non-threatening human approaches). Because fleeing presents both immediate costs and benefits to the fleerer, such as loss of foraging opportunities if initiated too soon and the threat of predation if initiated too late, the individual fleerer will initiate flight only after assessing that its benefits outweigh the costs (Ydenberg and Dill, 1986).

Therefore, measuring an animal's FID in response to a pursuer can provide an idea of how threatening that pursuer is perceived to be, with greater FIDs indicating greater perceived threat.

While past research has found that greater exposure to regular human activity has been shown to decrease FIDs in gray squirrels (Engelhardt and Weladji, 2011), exemplifying the effect of desensitization on the antipredator behavior of habituated wildlife, there is still a lack of similar studies conducted on other solitary free-living mammal species. Studies examining anthropogenic impacts on a wide array of taxa help inform policy and conservation efforts (Blicharska et al., 2019), and examining anthropogenic impacts on wildlife behavior is especially important for species that cohabitate with humans. Studying solitary species specifically is also important, as solitary species comprise approximately 22% of all studied mammal species (Makuya and Schradin, 2023). Additionally, while group-living species often rely on the vigilance of multiple group members to detect threats (Olson et al., 2015), solitary species rely on their own vigilance, potentially making changes in their antipredator behavior more impactful to their individual survival outcomes.

In this study, we investigated the anthropogenic impacts on antipredator behavior of two solitary small mammals that are common in rural, montane environments, the golden-mantled ground squirrel (GMGS) and least chipmunk (CPMK). We conducted FID trials on individual GMGS and CPMK exposed to varying levels of human disturbance to determine if GMGS and CPMK who experienced greater levels of human exposure have, on average, shorter FIDs in comparison to the lesser-exposed GMGS and CPMK populations as a result of habituation to non-threatening human approaches, in accordance with past trends found in other taxa. We used generalized linear mixed effect models to assess the effect of level of human disturbance (determined by distance to markers of human disturbance such as roads, trails, buildings, and

other paved surfaces and the proportion of these markers within a buffer range of each trial), starting distance, and surrounding substrate on FID.

Methods

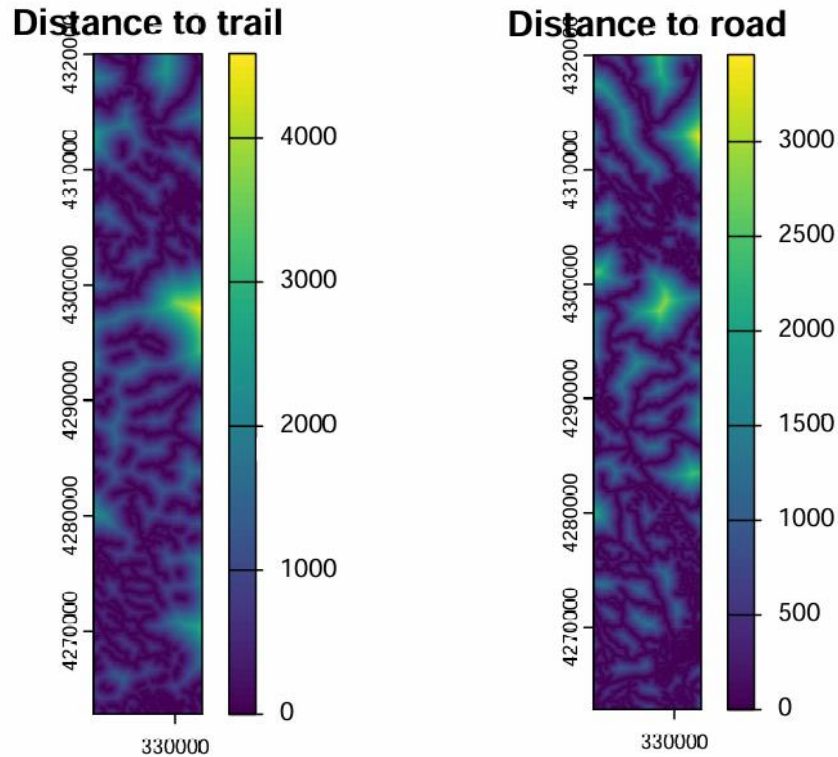
Study sites and animals

Wild GMGS and CPMK were studied along various sites in and around the Rocky Mountain Biological Laboratory (RMBL) located in Crested Butte, CO, which has been used by researchers since 1928. During both species' peak active season (May to August) they coexist alongside anywhere up to 180 resident researchers and staff at RMBL along with exposure to thousands of tourists passing through the townsite. According to RMBL's June 2025 newsletter, approximately 21,000 people visited the RMBL Visitor Center in Summer 2024. Since RMBL's founding, local GMGS and CPMK populations have been exposed to growing levels of human disturbance which can be demonstrated through measures such as number of researchers and projects at RMBL and hotel occupancy rates in nearby Crested Butte (Uchida and Blumstein, 2021), creating a gradient of levels of human disturbance in areas around RMBL.

GMGS have been studied at RMBL for 35 years (see Wells and Van Vuren, 2017). GMGS are routinely trapped to record seasonal changes in mass, as well as to renew permanent identifiers such as numbered ear tags and unique dye marks. Individual GMGS are observed daily during their peak activity hours of 7:30-11am and 2-5pm between mid May through late August, as researchers record unique individuals' locations, behavioral activity, and interspecies and intraspecies interactions. While not harmful to the animals, being handled and observed is presumably aversive, therefore GMGS researchers could be viewed by GMGS as more threatening compared to non-GMGS researchers, a factor that could increase FIDs of GMGS

within the RMBL Townsite. Additionally, increased vehicle traffic in this area during the summer season was found to be a direct cause of mortality, with 1 in 10 female GMGS at RMBL dying in roadkill events (Burgstahler et al., 2023), and could potentially be perceived as a threat affecting FIDs in RMBL GMGS and RMBL CPMK located near roads.

We chose 11 sites (RMBL Townsite, Crested Butte, Peanut Lake, Magic Meadows, Upper Loop, Sage Meadow, Emerald Lake, Avery Campground, Snodgrass Trail, Hartman Rocks, South Gothic) containing various levels of human disturbance with both GMGS and CPMK for conducting our FID trials. Level of human disturbance for the location of each trial was assessed by several metrics using RASTER grid systems to analyze land cover. Individual rasters were created to calculate each trial's distance to roads and distance to trails in meters using US Census Bureau data and RMBL's own GIS data respectively. Proportion of impervious surfaces (defined as roads, buildings, and other paved surfaces) within a buffer range of each trial's location was also obtained using RMBL's GIS data published through the RMBL Spatial Data Platform. Buffer range radius was determined by taking $\frac{1}{2}$ of each species' average home range width, with GMGS buffers having a radius of 75 meters and CPMK buffers having a radius of 50 meters. Surrounding substrate around the animal's location, such as dirt, rock, log, low vegetation and high vegetation (categorized by whether or not the vegetation greatly obstructed the animal's view) was also recorded.



Rasters created to aid in calculating distance to trail and distance to road.

FID Protocol

To measure perceived threat, we conducted FID trials using a protocol outlined in (Blumstein et al., 2023) across July 2025 in all sites of varying levels of human disturbance. Sites were patrolled between 8-11am until a relaxed GMGS or CPMK was found. “Relaxed” was defined as when the animal was not facing towards the researcher in alarm, halting their current task to go alert, or showing signs of distress such as alarm calling. The animal was approached at a rate of 0.5 m/s until flight was initiated. Flags were dropped at the location the approach was started, at alert distance (distance the animal became alert by looking around or halting their activity), at FID, and at the starting location of the animal before fleeing. A meter tape was used to measure the distance between each flag. Surrounding substrate (high vegetation,

low vegetation, dirt, rocks, log), starting behavior (foraging or feeding, four-legged stand, two-legged stand, running), and slope of approach (measured in degrees), were also noted. A GPS coordinate was collected at each animal's starting location to help identify the surrounding area's level of human disturbance (see rasters above). After completing a trial testing a GMGS, researchers traveled a minimum 150 meters, or the approximate average home range width for a female GMGS (Nguyen et al., 2024), from the last trial location before attempting to search for another animal to avoid retesting the same individual, unless individuals could be reasonably distinguished through strong inference (i.e. a squirrel not being able to travel the distance a second squirrel was found within the period between both trials). For trials testing CPMK, researchers traveled a minimum 100 meters, or the approximate average home range width for a female least chipmunk (Bergstrom, 1988) from the last trial location before attempting to search for another animal to avoid retesting the same individual, unless strong inference could distinguish between the two individuals.

Statistical Analysis

We collected 50 GMGS FID trials and 40 CPMK samples across a gradient of levels of human disturbance. A generalized linear mixed effect model was used for both species with level of human disturbance as the independent variable and FID as the dependent variable, using the 'lme4' package within R (Bates et al.). We included a random effect of site to account for any unmeasured variation among locations, and the following fixed effects: starting distance (m), substrate, distance to roads, distance to trails, proportion of impervious surfaces within a buffer range) . All numeric variables were scaled. As both FID and starting distance were right-skewed, we log-transformed (log base 10) each of them to approximate a normal distribution.

Results

In the CPMK model, starting distance had a significant positive effect on FID (Table 1), indicating that individuals fled at longer distances in trials with longer starting distances. In contrast, proportion of impervious surfaces had a significant negative effect on FID: in locations with a greater amount of human-made structures, individuals fled at shorter distances. While not statistically significant, the effect of distance to road and distance to trail was reliably positive, indicating greater distances to the nearest road was associated with longer FIDs.

In the GMGS model, only starting distance was significant (Table 2). It also had a positive coefficient, similarly indicating that larger starting distances had significant correlation to higher FIDs. Distance to roads and distance to trails did not have significance. However, substrate log, substrate low vegetation and substrate high vegetation were reliably negative, indicating that when the squirrel was on a log or in low vegetation or high vegetation, FIDs tended to be smaller. Distance to road was also found to be reliably positive, indicating greater distances to the nearest road was associated with longer FIDs.

Chipmunk Results

Variable	Estimate	Std. Error	df	t value	p-value	Significance
(Intercept)	0.48629	0.05492	31	8.854	5.40e-10	***
Substrate: high veg	0.02930	0.06965	31	0.421	0.6769	
Substrate: log	-0.06364	0.08732	31	-0.729	0.4716	
Substrate: low veg	0.01545	0.08327	31	0.186	0.8540	
Substrate: rock	0.02566	0.07127	31	0.360	0.7213	
Distance to road (scaled)	0.02949	0.02486	31	1.186	0.2445	
Distance to trail (scaled)	0.03492	0.02367	31	1.475	0.1503	
Impervious surface % (scaled)	-0.04913	0.02372	31	-2.071	0.0467	*
Starting distance (scaled)	0.13510	0.02337	31	5.782	2.28e-06	***

Table 1: CPMK Statistical Results

Substrate categories listed were calculated in comparison to a reference category, substrate dirt.

Squirrel Results

Variable	Estimate	Std. Error	df	t value	p-value	Significance
(Intercept)	0.798594	0.060680	24.556127	13.161	1.27e-12	***
Substrate: high veg	-0.152587	0.087262	40.765370	-1.749	0.0879	.
Substrate: log	-0.196815	0.108664	41.629545	-1.811	0.0773	.
Substrate: low veg	-0.109469	0.090516	41.662375	-1.209	0.2333	
Substrate: rock	-0.026207	0.067068	40.373234	-0.391	0.6980	
Distance to road (scaled)	0.035952	0.030619	39.306115	1.174	0.2474	
Distance to trail (scaled)	-0.003858	0.042691	7.712090	-0.090	0.9303	
Impervious surface (scaled)	0.003289	0.030115	36.273903	0.109	0.9136	
Starting distance (scaled)	0.139965	0.027173	38.243589	5.151	8.15e-06	***

Table 2: GMGS Statistical Results

Substrate categories listed were calculated in comparison to a reference category, substrate dirt.

Discussion

Our results did find a statistically significant correlation between a marker of human disturbance, proportion of impervious surfaces within a buffer range of the animal, and CPMK

FIDs, supporting the idea that the CPMK populations we studied that experience greater exposure to human disturbance have habituated. This follows the trend seen in many studies examining the effect of long-term human disturbance on changes in wildlife behavior, as mentioned above. These results were found even despite a smaller sample size, indicating that with further data collection, more precise estimates for the effects of distances to road or trail could be determined.

While our model did not show as many significant results for GMGS than we anticipated, we found distance to road to be reliably positive, meaning that squirrels tended to flee sooner and at greater distances the further they were from roads, a marker of human use. Additionally, substrate log, substrate low vegetation and substrate high vegetation were reliably negative, indicating that when the squirrel was on a log or in low vegetation or high vegetation, FIDs tended to be smaller. For substrate low vegetation and high vegetation, these effects are likely tied to visibility level, as vegetation likely made it harder to notice pursuers. A negative effect for substrate log was unexpected however, and there are many possible explanations for this. One possible explanation could be that since GMGS on logs were typically found on toppled trees within forests, that the forests' natural vegetation and activity made it harder to notice the pursuer and therefore their FIDs were shorter. Alternatively, GMGS that had more rocks or perches within their home range were found to have higher survival rate (Aliperti et al., 2022), so another explanation could suggest that when squirrels had more visibility as a result of being off the ground, they were more confident in their ability to flee when necessary, and therefore waited longer to do so. Interestingly, substrate rock showed little significance despite the assumption that such substrate would provide greater visibility, but this could potentially be due to the broad categorization of the substrate overall. For example, a squirrel found on a single

rock in the middle of an open field versus on a rock in the middle of a steep rockpile were both counted as substrate rock, resulting in a greater variety of environmental conditions that these trials were conducted in.

It is also interesting that substrate type showed more significance for GMGS versus CPMK, but one possible explanation could be the size differences between GMGS and CPMK. CPMK are much smaller in comparison to GMGS, with adult CPMK ranging from less than 7 inches to 9 inches in length, versus adult GMGS who are 9 inches to 12 inches in length (National Park Service, August 9, 2025). This larger size could result in a higher visibility benefit from different substrates for GMGS, for example, a GMGS would likely be able to see more on top of a rock than a CPMK due to their longer height, especially if standing upon their hind legs, a common behavior they exhibit.

Starting distance was also highly significant for both GMGS and CPMK, which follows previous literature suggesting that starting distance is a strong predictor for FID (Blumstein 2003). This supports the economic model proposed by Ydenberg and Dill (1986) that predicts that species use dynamic risk assessment to determine the optimal time to flee. If an animal becomes aware of a pursuer from a greater distance, then they may choose to flee sooner to minimize the cost of their escape. For example, if an animal escapes sooner, they may not have to flee at maximum velocity to get away safely, or exert more attention monitoring a pursuer for a greater period of time (Blumstein 2003).

Overall, despite a relatively small sample size and limited variety of study sites, our results still provide evidence to support our initial prediction of greater levels of human disturbance being correlated with shorter FIDs as a result of habituation to human approaches, indicating that over time, repeated exposure to human activity leads to shifts in wildlife

behaviors for montane ground squirrels and chipmunks. Our study contributes to the growing research on anthropogenic effects on wildlife behavior and expands the variety of taxa examined, reinforcing findings in past studies on this topic.

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