IDAHO DEPARTMENT OF FISH AND GAME

Ed Schriever, Director

Project F18AF01192

NIDGS Daily Activity Patterns
Cooperative Endangered Species Conservation

Final Report

Grant Performance Period
August 13, 2018 to June 30, 2020

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September 2020
Boise, Idaho

TRADITIONAL SECTION 6
FINAL PERFORMANCE REPORT

1. **State:** Idaho

   Grant number: F18AF01192

   Grant name: NIDGS Daily Activity Patterns

2. **Report Period:** October 1, 2019 to June 30, 2020

   Report due date: September 28, 2020

3. **Location of work:** Adams County

4. **Objectives**

   (1) Document the percent of time that northern Idaho ground squirrels (*Urocitellus brunneus*; NIDGS) spend above ground and how the percent varies throughout the day
   (2) Document the relationship between a suite of extrinsic factors and the percent of time that NIDGS spend foraging above ground
   (3) Compare above-ground patterns between treated (canopy thinning and prescribed fire) and control areas in the context of foraging efficiency (i.e., less time above ground equates to greater efficiency in foraging)

5. **If the work in this grant was part of a larger undertaking with other components and funding, present a brief overview of the larger activity and the role of this project.**

   This project was part of an overarching, ongoing study to examine NIDGS response to forest restoration treatments (thinning and burning) that was initiated in 2012 (Allison et al. 2018; Goldberg et al. 2015, 2020). The overarching study is led by the Idaho Cooperative Fish and Wildlife Research Unit at the University of Idaho (UI) in partnership with biologists, foresters, and fuels specialists on the Payette National Forest; species expert Dr. Eric Yensen, retired, College of Idaho; U.S. Fish and Wildlife Service biologists; Idaho Department of Fish and Game (IDFG); and private landowners. This project complements the larger research effort by examining aspects of data that are not the focus of habitat treatments. Specifically, >200 individual NIDGS are live-trapped, marked, and released each year as part of the research on forest restoration treatments. A subset of these individuals are equipped with radio collars that have a small light logger attached. During 2017–2019 we used these same collared squirrels, and specifically the data from the light loggers, to address questions related to daily activity patterns.

   To obtain a sufficient sample size to achieve the objectives listed in #4 above, this project extended over several years and was supported by several funding sources in addition to this Section 6 grant. All of the 2017 field work, and much of the field work in 2018–2020, was supported by the larger work on habitat treatments funded primarily by the Payette National

Forest as part of the national Collaborative Forest Landscape Restoration Program (CFLRP). Additional support was provided by the U.S. Fish and Wildlife Service, U.S. Geological Survey, and IDFG. Section 6 grant F17AF01083 purchased radio collars and light loggers and supported preliminary data analysis in 2018. This Section 6 grant (F18AF01192) purchased collars and light loggers deployed in summer 2019; supported field work in spring 2019 to recover collars deployed in 2018; and supported data analysis. The OX Ranch, a private landholding in Bear, Idaho, supported this project by providing housing for field technicians and access to study sites. The OX Ranch entered into a Safe Harbor Agreement (SHA) with the U.S. Fish and Wildlife Service and IDFG in 2009 to help meet recovery goals for NIDGS. The SHA covers 4,227 acres on the OX Ranch and encompasses a significant portion of the NIDGS population.

6. Describe how the objectives were met.

METHODS

Our interest in daily activity patterns was to (1) improve annual population monitoring surveys for NIDGS (Wagner and Evans Mack 2019) by quantifying when squirrels were most likely to be above ground and available to be counted on surveys, and (2) use time spent above ground as a proxy for time spent foraging to explore habitat differences. Squirrels may need to forage above ground longer (either more foraging time per day or by delaying hibernation immergence) in relatively poor habitat to obtain sufficient energy and nutrients. Additionally, squirrels face trade-offs between foraging and predation risk (Verdolin 2006). Individuals with poor body condition may tolerate higher predation risk to increase foraging time above ground (Bateson 2002). In fact, Goldberg (2018) found that NIDGS with lower residual body mass immerged into hibernation later (i.e., remained active longer) than those with high residual body mass.

During 2017–2019 we deployed 92 collars (33 in 2017, 29 in 2018, and 30 in 2019) on 83 individual adult and yearling NIDGS (43 females and 40 males) at 7 study sites. We captured squirrels later in their active season (mid-June to mid-July) and we collared only squirrels with a body mass ≥140 g to minimize the likelihood of a collared squirrel growing too large for its collar before hibernation. We collared ≤33% of adult squirrels at any one site (determined via spring capture numbers from the larger restoration study). We attempted to distribute collars equitably between males and females within and among study sites. We recovered radio collars and their associated light loggers each spring following deployment during early season live-trapping sessions, assisted by radio telemetry to locate collared squirrels.

We used 2 types of radio-transmitters: HOLOHIL BD-2C transmitters and Biotrack CTx transmitters. The HOLOHIL transmitters were standard VHF radio-transmitters that continuously emitted a signal until the battery died (~10 weeks). The Biotrack transmitters were programmable VHF units; we pre-programmed the transmitters to emit signals on specified dates spread across parts of 2 active seasons (the summer a squirrel was collared and the following spring). Doing so increased the probability of recovering transmitters the spring after they were deployed (post-hibernation).

We attached light loggers (Migrate Technology C-65 SUPER geolocators) to radio-collars with a combination of glue, epoxy, and nylon wrapping. Collars fitted with light loggers allowed us to determine when a squirrel was above or below ground. Squirrels were primarily foraging when they were above ground (pers. observ.). The light loggers measured light levels every minute and recorded the maximum of those measurements across 5-min time bins (i.e., 0:00–0:05, 0:06–0:10, etc.; Figure 1). We also placed a string of 5 radio-collars equipped with light loggers into a NIDGS nest burrow (determined via radio-telemetry) to determine the best cutoff value for documenting above-ground versus below-ground activity. We placed the string of 5 radio-collars in the following positions in relation to the mouth of the nest burrow: outside the burrow in full sun, in the burrow mouth, 5 cm into the burrow, 15 cm into the burrow, and 25 cm into the burrow. We placed a 6th logger in full shade to account for cloudy days or squirrels choosing to forage in shady areas.

Based on the light measurements recorded by these 6 loggers and their known proximity to the ground surface under various sky conditions, we defined squirrels as being above ground during a 5-min bin if the reported maximum illuminance for that 5-min bin was ≥1000 lux. The logger 5 cm below the nest burrow entrance only rarely recorded values >1000 lux and the 3 loggers >5 cm below the entrance never recorded values >1000 lux. Conversely, the 3 above-ground loggers (sun and shade) recorded values >1000 lux on 100% of the 5-min intervals (during the daylight hours when squirrels were active).

We measured ambient above-ground illuminance and temperature with 2 Onset HOBO pendant light/temperature loggers: one logger placed directly in the sun to measure ambient light and a second logger placed in a constantly shaded area to measure ambient temperature (temperature measurements are unreliable when loggers receive direct sunlight). We recorded snow depth measurements from trail cameras aimed at snow gauges placed within NIDGS active-season site footprints at each study site. We programmed the trail cameras to take a picture of the snow gauge each morning between 9:00 and 10:00. We took daily precipitation data from the nearest SNOTEL station (West Branch), which was ~10 km from our nearest study site and approximately the same elevation as our highest elevation study site (~1,700 m). We used daily precipitation data from the SNOTEL station because we did not have site-specific precipitation data from our study sites and felt the available hourly precipitation would not match up well with our study sites as the weather can be locally patchy in our mountainous study area.

We took a two-stage modeling approach to determine which extrinsic factors affect above-ground foraging activity of NIDGS. We modeled the likelihood of a squirrel being above or below ground during a given 5-min bin as a binomial distribution with a logit link function. We restricted our analyses to include only daylight hours (determined via our site-specific light loggers in full sun) when squirrels might be foraging. We excluded 5664 daylight time bins for which we did not have instantaneous ambient temperature and light data and an additional 1060 bins during which our “shaded light logger” at a site was exposed to full sun (≥100,000 lux). We excluded days on which we collared squirrels, squirrels immerged into hibernation, squirrels emerged from hibernation, and squirrels lost collars or had collars removed. We excluded the 3 days before a squirrel immerged into hibernation when known, the first day after a squirrel emerged from hibernation, and any additional days before a squirrel first spent 100 minutes above ground in a single day. In summary, we only included complete days with light logger data during which a squirrel was fully active and foraging. For 9 squirrels of unknown age class the year they were collared, we used body mass from squirrels of known age class collected at our study sites between 2013 and 2020 to assign as yearling or adult.

We first built a generalized linear mixed-effects model with the lme4 package (Bates et al. 2019) in Program R (R Core Team 2020) to investigate the effects of time and weather variables on above-ground foraging activity of squirrels. We built a global model with a random effect for individual squirrel ID and fixed effects for 7 explanatory variables: 1) year, 2) Julian day (quadratic), 3) proportional time of day (i.e., we scaled daylight hours for each day from 0 to 1; 4th degree polynomial), 4) ambient above-ground light intensity (quadratic), 5) ambient above-ground temperature (quadratic), 6) daily precipitation, and 7) daily snow depth. We compared all subsets of the global model and determined the top model by Akaike's Information Criterion corrected for small sample size (AICc; Burnham and Anderson 2002). We then used the top model from phase one above, and added 3 additional variables for a second round of model selection: site, sex, and age class. We again compared all model subsets for these 3 variables to determine the best overall model (while using the best model from phase one above as the informed null model).

We did not have the ability to model the effects of experimental restoration treatments (Objective 3), because only 1 study site (Fawn Creek) had been fully treated. We therefore investigated change in squirrel foraging activity at Fawn Creek pre- versus post-treatment. Fawn Creek was thinned in fall 2017 and burned in fall 2018; we considered 2017 and 2018 to be pre-treatment and 2019 and 2020 to be post-treatment. We plugged our light logger data from Fawn Creek only into our most parsimonious overall activity model and substituted pre- and post-treatment for the individual year effect.

RESULTS

We recovered 69 functional light loggers (75% of the 92 deployed) from 62 individual NIDGS. We were unable to locate and recover the remaining 23 light loggers, presumably because the squirrels were depredated/scavenged, immigrated, and/or the collars failed. The light loggers recorded 1659 complete squirrel days of activity data. This included data from summer 2017 through spring 2020 and covered dates from 20 March to 2 August. Two squirrels died within a few days of collaring; we excluded all data from these 2 squirrels to prevent effects of poor collar fit from biasing the results.

NIDGS above-ground activity followed a diurnal pattern: squirrels spent time above ground between 7:00 and 21:30, though these endpoints shifted seasonally. Within those daylight hours, the raw data suggested a bimodal activity pattern during summer months (June–August), with peaks in the morning and evening (Figure 1).

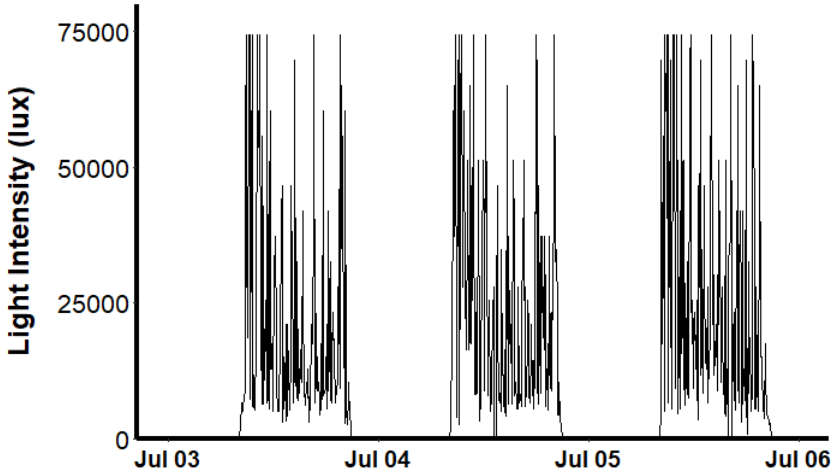

Figure 1. Example of light intensity data recorded by a light logger attached to a northern Idaho ground squirrel. We considered squirrels to be below ground at light intensity levels <1000 lux.

During March–May, female squirrels had a bimodal activity pattern, again with a peak in the morning and the evening, but males had a unimodal activity pattern, with a peak in the afternoon. Squirrels spent an average of 487 min/day (SD = 220 min) above ground. There were, however, significant differences between time spent above ground in summer (June–August) and spring (March–May; $t = 33.4$, $df = 747$, $p < 0.0001$). Squirrels spent 126% more time per day above ground after being collared in summer (mean = 583 min, SD = 149 min) than they did after emerging from hibernation in spring 2020 (mean = 258 min, SD = 192 min; Figure 2). Males spent 6% more time per day above ground (596 min/day, SD = 142 min) than females (564 min/day, SD = 157 min) during summer ($t = 3.6$, $df = 998$, $p < 0.001$) and females spent 42% more time per day above ground (319 min/day, SD = 162 min) than males (224.8 min/day, SD = 199 min) in spring ($t = 5.6$, $df = 415$, $p < 0.0001$; Figure 3). These raw data, however, do not account for individual squirrel behavior or weather conditions.

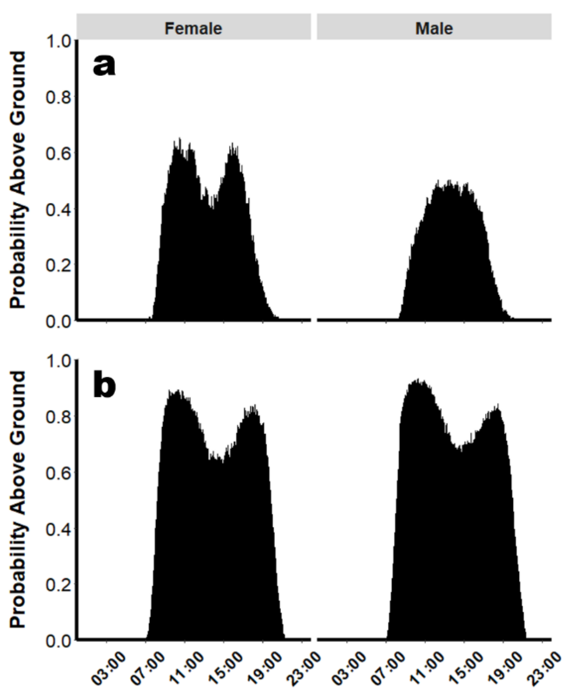

Figure 2. Probability that a northern Idaho ground squirrel is above ground during a given time bin for male and female squirrels in a) spring (March-May) and b) summer (June-August). The y-axis for both plots is the proportion of all bins among squirrel days at a given time squirrels were above ground.

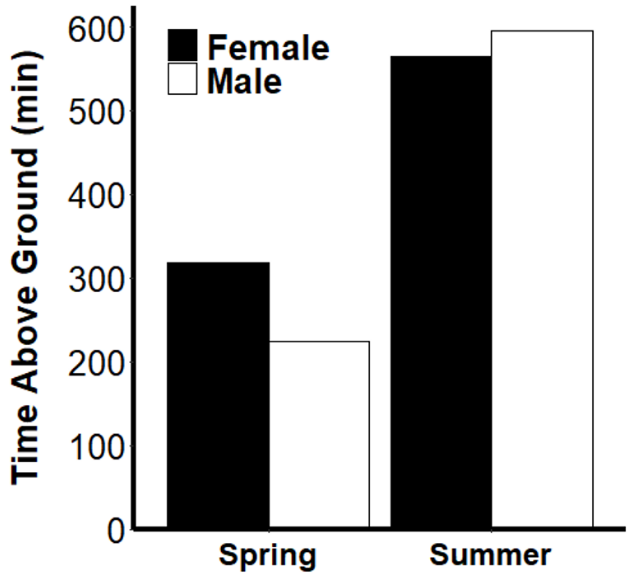

Figure 3. Mean number of minutes per day spent above ground by male and female northern Idaho ground squirrels in spring (March/April/May) and summer (June/July/August).

After truncating our data for the modeling effort, 1318 active squirrel days spread across 59 individual squirrels remained. This included data from summer 2017 through spring 2020 and covered dates from 30 March to 28 July. The top stage 1 model designed to ascertain which factors affect the probability of being above ground included 7 factors: year, Julian day (quadratic), proportional time of day (4th degree polynomial), ambient above-ground light intensity (quadratic), ambient above-ground temperature (quadratic), total daily precipitation, and snow depth (Table 1). There was a competing model (<2.00 ΔAICc) that did not include an effect for snow depth; all other models were less parsimonious than the top model (≥2.00 ΔAICc). We excluded snow depth from the stage 2 modeling effort because its inclusion in the stage 1 model failed to improve the model by >2.00 ΔAICc. The top stage 2 model added sex to the stage 1 model (Table 2). There were 4 additional competing models (<2.00 ΔAICc) that included various combinations of sex, age class, and site, suggesting some model uncertainty. The effects of sex, age class, and site, however, were never significant ($p > 0.5$). We, therefore, present marginal effects from the simplest of the competing models, which included only the effects of the time and weather variables (i.e., the informed null model derived from stage 1).

Table 1. Top models from stage 1 generalized linear mixed-effects model selection based on models designed to explain variation in above-ground foraging activity of northern Idaho ground squirrels. The global stage 1 model included 7 fixed effects for time and weather variables (year, Julian day, proportional time of day, ambient light intensity, ambient temperature, total daily precipitation, and snow depth). All models included a random effect for individual squirrel ID. The table includes models with ≤2.00 ΔAICc, the global model (the top model here), and the null model.

Model	AICc	ΔAICc	w_i
~Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip. + Snow (Global)	53309.15	0.00	0.62
~Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip.	53310.10	0.95	0.38
~Null	90187.26	36878.12	0.00

Table 2. Best models from stage 2 generalized linear mixed-effects model selection designed to explain variation in above-ground foraging activity of northern Idaho ground squirrels. The global model included sex, age class, and site, as well as the variables from the top model from stage 1 (see Table 1). All models included a random effect for individual squirrel ID. The table includes all models with ≤2.00 ΔAICc, the global model, and the informed null model (i.e., the best fit stage 1 model).

Model	AICc	ΔAICc	w_i
~Sex + Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip.	53309.90	0.00	0.24
~Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip. (Informed Null)	53310.10	0.20	0.22
~Site + Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip.	53310.77	0.87	0.15
~Sex + Site + Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip.	53311.60	1.70	0.10
~Sex + Age + Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip.	53311.61	1.71	0.10
~Sex + Age + Site + Year + J. Day^2 + Prop. Daylight Hrs^4 + Light Intensity^2 + Temp.^{2} + Precip. (Global)	53313.41	3.51	0.04

The marginal-effects output from the model (holding all other fixed and random effects constant at their mean) shows that squirrels spent more time foraging above ground in 2019 and 2020 than in 2017 and 2018 (Figure 4a). Within a year, the probability of a squirrel being above ground increased throughout the spring, peaking in late June, shortly before squirrels begin to immerge into hibernation (Figure 4b). While the model suggests a 4th degree polynomial is the best fit for squirrel activity across a given day, the bimodal activity pattern seen in the raw data is largely flattened once we accounted for seasonality and environmental conditions (Figure 4c). Squirrel activity increased rapidly from 10% through 30% of the way through daylight hours (i.e., early morning) as squirrels emerged from their night nests before dipping slightly and ultimately leveling off throughout the afternoon and evening. Squirrels rapidly immerged into their night nests beginning at 90% of the way through daylight hours.

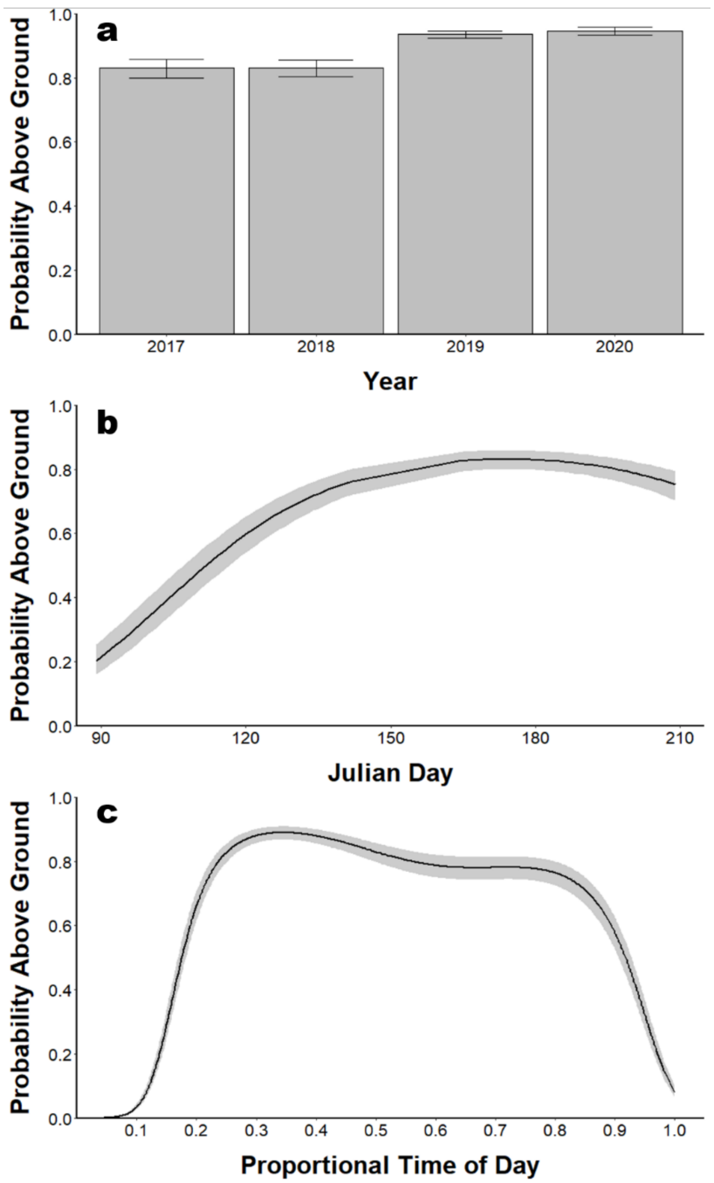

Figure 4. Marginal effects (±95% CI) for time variables a) year, b) Julian day, and c) proportional time of day (daylight hours scaled from 0 to 1 to account for seasonal shifts in daylight hours) included in our top generalized linear mixed effects model explaining variation in northern Idaho ground squirrel above-ground activity. The y-axis for all plots is probability of a squirrel being above ground during a 5-minute time bin.

Squirrels were more likely to remain underground during periods of high ambient solar radiation (Figure 5a). Ambient temperature per se also significantly impacted above-ground activity. Squirrels largely stayed underground at temperatures below 0ºC; squirrels were most active at temperatures between 15ºC and 30ºC (Figure 5b). The model suggests a negative association between total daily precipitation and above-ground squirrel activity (Figure 5c). We expect this association would be even stronger with site-specific instantaneous precipitation data given the possibility of spatial and temporal mismatches between the daily precipitation data from the West Branch SNOTEL station and our study sites.

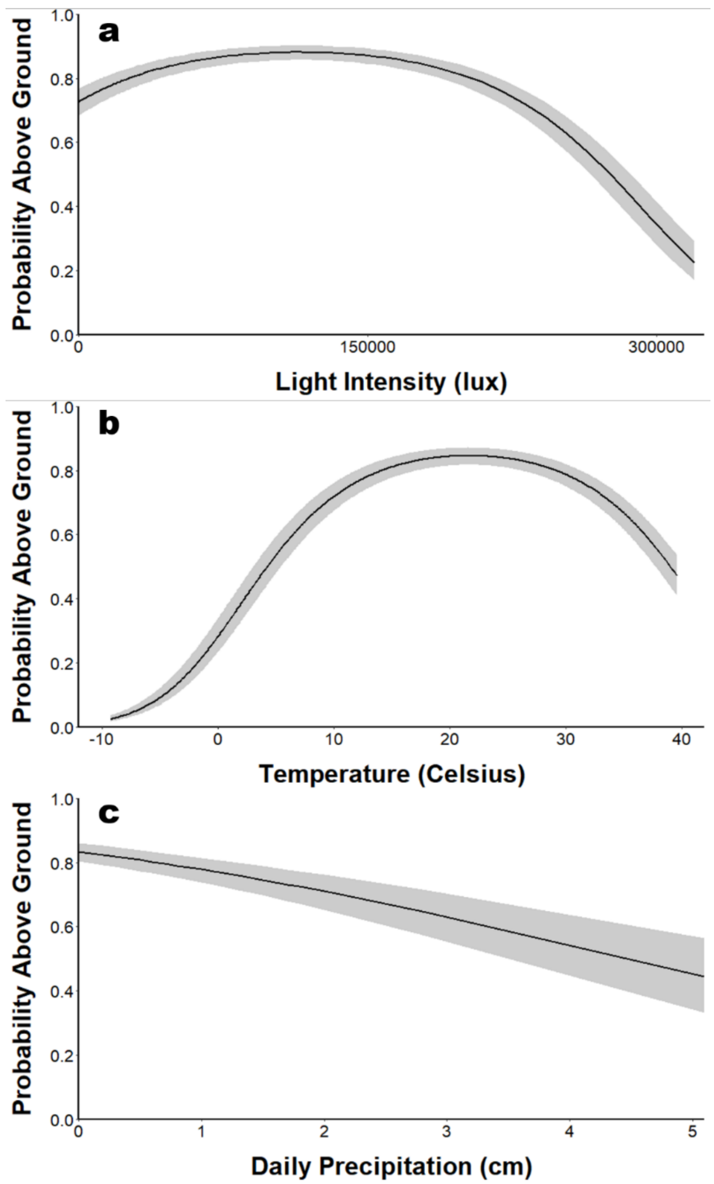

Figure 5. Marginal effects (±95% CI) for weather variables a) ambient light intensity, b) ambient temperature, and c) total daily precipitation included in our top model designed to explain variation in above-ground foraging activity of northern Idaho ground squirrels. The y-axis for all plots is probability of a squirrel being above ground during a 5-minute time bin.

Squirrels at our only treated site (Fawn Creek) spent more time foraging above ground post-treatment than pre-treatment (Figure 6). The post-treatment increase in time spent above ground, however, is the same effect we saw between 2017 and 2018 (pre-treatment) and 2019 and 2020 (post-treatment) in our overall model, which included data from all study sites, suggesting a general trend across sites rather than a treatment effect.

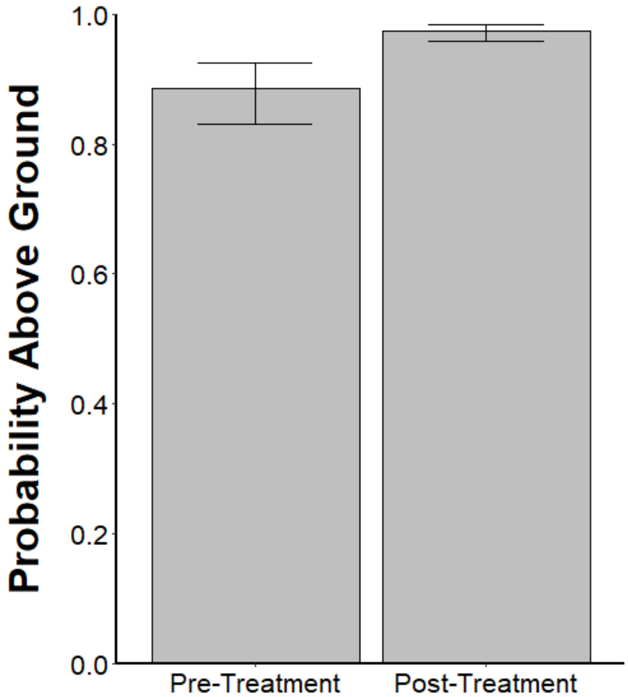

Figure 6. Marginal effects plot (±95% CI) showing the effects of forest restoration treatment (pre- vs. post-treatment) on above-ground foraging activity of squirrels at our Fawn Creek study site. The y-axis is the probability of a squirrel being above ground during a 5-minute time bin. The model includes data from 256 active squirrel days from summer 2017 through spring 2020 spread across 9 individual squirrels.

Our results provide the first quantitative description of above-ground activity for the threatened NIDGS. Squirrels spent most of their above-ground time foraging, though some above-ground time is spent on other activities (e.g., scanning for predators or interacting with other squirrels). The above-ground activity of NIDGS confirmed a pattern familiar to us from our field observations and trapping effort: above-ground activity peaked in the morning before a lull in the afternoon, followed by a second peak in the late afternoon/evening. Despite the mid-day lull in activity, squirrels foraged throughout daylight hours and were rarely so deep in their burrows for an entire 5-minute time bin that a light logger failed to register any illuminance.

The raw data showed differences in activity levels between males and females, but our most parsimonious model did not include an effect of sex. The best model did include sex, but sex was found to be non-significant ($p > 0.1$). We, however, did not have any collar data for males between late April and mid-June, and limited female data for that same period, when females are nursing and otherwise tending to pups in natal burrows. Williams et al. (2016) found significant differences in foraging activity between male and female arctic ground squirrels during lactation when forage was abundant. Future studies of NIDGS foraging activities should consider the time of the year when females are lactating to look for sex-specific differences in foraging patterns.

Affirming our field observations, our modeling effort suggests weather (i.e., thermal conditions) plays an important role in limiting above-ground activity and may explain the mid-afternoon lull depicted in the raw data. In this way, our work is in line with that of other light logger-based studies of ground squirrel activity (Long et al. 2005, Williams et al. 2014, Williams et al. 2016), which have found weather-driven thermal constraints to be the primary factor influencing daily activity patterns of ground squirrels. Our model, however, does suggest somewhat lower levels of midday activity regardless of weather. The decrease in activity during the afternoon could be because: 1) squirrels acquired sufficient energy and nutrients during the morning hours, 2) their relatively short digestive tracts are full, or 3) there were thermal constraints not entirely accounted for by our modeling effort (e.g., instantaneous precipitation and wind). If thermal constraints largely explain NIDGS activity patterns, climate change could be a threat to NIDGS populations, particularly if summer temperatures rise.

The role of forage availability as a factor influencing above-ground activity is unclear. Study site was not included in our most parsimonious model, though it was included in 2 competing models. This does not necessarily mean there are no differences in forage quality among sites, which could be masked by other site-level factors (e.g., precipitation). We did find differences among years in time spent foraging, which could reflect differences in forage availability driven by annual weather. These differences, however, could also reflect state-dependent foraging behavior if squirrels were playing “catch up” after late snowmelt in 2019 and 2020. Our model is unable to disentangle the effect of our restoration treatments from site effects on NIDGS foraging activity because only one study site for which we have light logger data has been fully treated (Fawn Creek).

The NIDGS is a rare species with a limited distribution (Yensen and Dyni 2020). Even within that already limited historic range, the squirrel is patchily distributed and mostly restricted to xeric, rocky scab meadows (U.S. Fish and Wildlife Service 2003). A primary hypothesis to explain these limitations is the degradation of foraging habitat by anthropogenic fire suppression. Negative effects of forage limitation may be exacerbated by the squirrels’ short active season (3–4 months for an individual squirrel). Our modeling suggests climate change may pose additional challenges to this montane species. Understanding the foraging behavior of this species is vital to recovery efforts. It is unclear how or indeed whether squirrels can respond to a simultaneous deterioration of forage and foraging (i.e., thermal) conditions and what consequences those responses (or lack thereof) may have on squirrel demography. Further research into the effects of forage quality on foraging activity and linking foraging behavior to fitness is required to provide best management guidelines to recover this threatened species.

7. Discuss differences between work anticipated in grant proposal and grant agreement, and that actually carried out with Federal Aid grant funds.

Objectives 1 and 2 were completed as anticipated. Objective 3 could not be fully addressed within the project timeframe due to complications that limited the Payette National Forest’s ability to complete experimental forest treatments on schedule and to the specifications desired. Exploration of differences in NIDGS foraging activity pre- and post-treatment will continue as part of the overarching research to which this project contributed.

8. List any publications or in-house reports resulting from this work.

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