



Ackerson Meadow Great Gray Owl Prey Inventory



The Ackerson South Meadow within Yosemite National Park, 1 August 2023.
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Ackerson Meadow Great Gray Owl Prey Inventory

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Abstract

The genetically unique subspecies (*Strix nebulosa yosemitensis*) of great gray owls in the Sierra Nevada are a primary focus of Yosemite National Park management activities, and understanding predator-prey relationships and the effects of habitat management on prey populations is essential to the continued persistence of the great gray owl. The recent Ackerson Meadow Restoration Project presents an opportunity to enhance habitat for prey species, ultimately benefiting the state-endangered great gray owl and many other species. However, information about great gray owl prey, and how management activities will impact prey, is unknown. This inventory focused on providing baseline data on great gray owl prey populations at the Ackerson Meadow Complex and Hodgdon Meadow, including variation in prey across sites and years, whether variation was related to vegetation or soil properties, and the suitability of a non-traditional method for assessing abundance change in great gray owl prey through time. We surveyed voles and gophers across two habitat types (forest and meadow) at three sites (Ackerson Main Meadow, Ackerson South Meadow, and Hodgdon Meadow) in 2023 and 2024. We used multiple methods to assess vole populations, including live-trapping, chew block removal, and camera trapping, and indirect estimates of gopher abundance via surveys for gopher activity. At each site, we also characterized a set of vegetation and soil properties. Overall, while there was some variation in prey population abundance estimates, we did not find strong consistent spatial or temporal variation in great gray owl prey populations across sites and through time, in part due to limited sample sizes across the survey period and many zeros in the final dataset. We found that soil wetness was the strongest predictor of great gray owl prey presence—positively associated with vole presence and negatively associated with gopher presence. Finally, we found that there were strong correlations between different measures of vole abundance, providing a potentially valuable indirect survey method for voles (chew blocks, with or without cameras). Overall, our results echo findings from previous surveys of vole and gopher populations, and point to new, less invasive management tools for surveying vole populations in wildland settings.

Acknowledgments

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Introduction

Great gray owls are large-bodied raptors that play a variety of roles, such as regulating prey, in ecosystems (Duncan and Hayward 1994). They are widely distributed and throughout their range in Asia and North America, the species is associated with boreal and montane coniferous forests (Duncan and Hayward 1994). The southernmost population of the species occurs in the southern Sierra Nevada mountains of North America and is disjunct from the rest of its range (Bull and Henjum 1990; Hull et al. 2010). The great gray owls in the Sierra Nevada are a genetically unique subspecies (*Strix nebulosa yosemitensis*) with a small population size and correspondingly low genetic diversity (Hull 2014; Hull et al. 2010); this population has been designated as a California State Endangered Species (California Natural Diversity Database, CNDDB 2025). Yosemite National Park (YOSE, or the park) is located centrally to this subspecies and park habitats are important to the continued persistence of the subspecies (Medley et al. 2011), so great gray owls are a special status bird species for the park and they are a primary focus of YOSE management activities.

Great gray owls nest near meadows, which they use as hunting grounds for small mammal prey (van Riper and van Wagtenonk 2006; van Riper et al. 2013). Habitat conditions have been found to influence predator-prey relationships and trophic dynamics of great gray owls (Janssen et al. 2007). Thus, understanding predator-prey relationships and the effects of habitat management on prey populations is essential to the continued persistence of the great gray owl. Studies in the Sierra Nevada have found that 90% of the great gray owl diet is comprised of voles (in particular *Microtus montanus* and *M. longicaudus*) and pocket gophers (*Thomomys* spp.) (Reid 1988). It has been suggested that because of the great gray owl's reliance on vole and pocket gopher populations, these prey species are more important in determining habitat selection than structural habitat components (van Riper et al. 2013). However, while understanding great gray owl ecology and management has been a focus of biological research in Yosemite (e.g., Medley et al. 2011), relatively little is known about the vole and pocket gopher populations that great gray owls depend on. Gophers and voles both use meadow habitats to varying degrees, but the specific meadow conditions they prefer vary by species. Some research has suggested that more frequent flooding and wetter meadow areas will result in less gopher activity (Ingles 1949, 1952) and previous work by Kalinowski et al. (2014) found that gopher abundance was negatively associated with site wetness and positively associated with different aspects of vegetation. Similarly, Kalinowski et al. (2014) found that vole presence was positively associated with meadow vegetation height and corn lily dominance, in the region including and north of Yosemite (Kalinowski et al. 2014).

The majority of the *S. nebulosa yosemitensis* population resides in Yosemite and the park is critical to the persistence of this subspecies (Ackerson Meadow Restoration Environmental Assessment 2021; Medley et al. 2011). Recent park management actions have the potential to alter great gray owl habitat and prey populations, including a recent large effort to restore the hydrology at the Ackerson Meadow complex. Yosemite National Park acquired much of the Ackerson Meadow complex, on the western border of the park (Figure 1), through a land transfer in 2016 (Ackerson Meadow

Restoration Environmental Assessment 2021), and jointly manages it with the adjacent Stanislaus National Forest. The 230-acre meadow complex represents one of the most extensive mid-elevation meadow systems in the Sierra Nevada and is the largest such meadow in Yosemite National Park, and it consequently has been identified as a regional conservation priority (Ackerson Meadow Restoration Environmental Assessment 2021). However, after more than a century of human impacts including extensive cattle grazing, the stream channel running through the meadow is severely eroded and the surrounding riparian habitat has been correspondingly degraded (Ackerson Meadow Restoration Environmental Assessment 2021). In 2020, Yosemite National Park and the Stanislaus National Forest initiated a historic project to restore the wetland and ecological functionality of the Ackerson Meadow complex, by filling the incised channel with soil and organic materials, raising the water table, and installing native plants (Ackerson Meadow Restoration Environmental Assessment 2021). These changes overall are expected to return the Ackerson Meadow complex to a wet meadow, with particularly significant changes to the more northerly, main meadow within the Ackerson complex (hereafter called Ackerson Main), which may have implications for great gray owl prey activity (e.g., there may be potentially less gopher and more vole activity; Kalinowski et al. 2014). The Ackerson Meadow Restoration Project presents an opportunity to enhance habitat for prey species, ultimately benefiting the state-endangered great gray owl and many other species. However, information about great gray owl prey, and how management activities will impact prey in the Ackerson Main Meadow, is unknown.

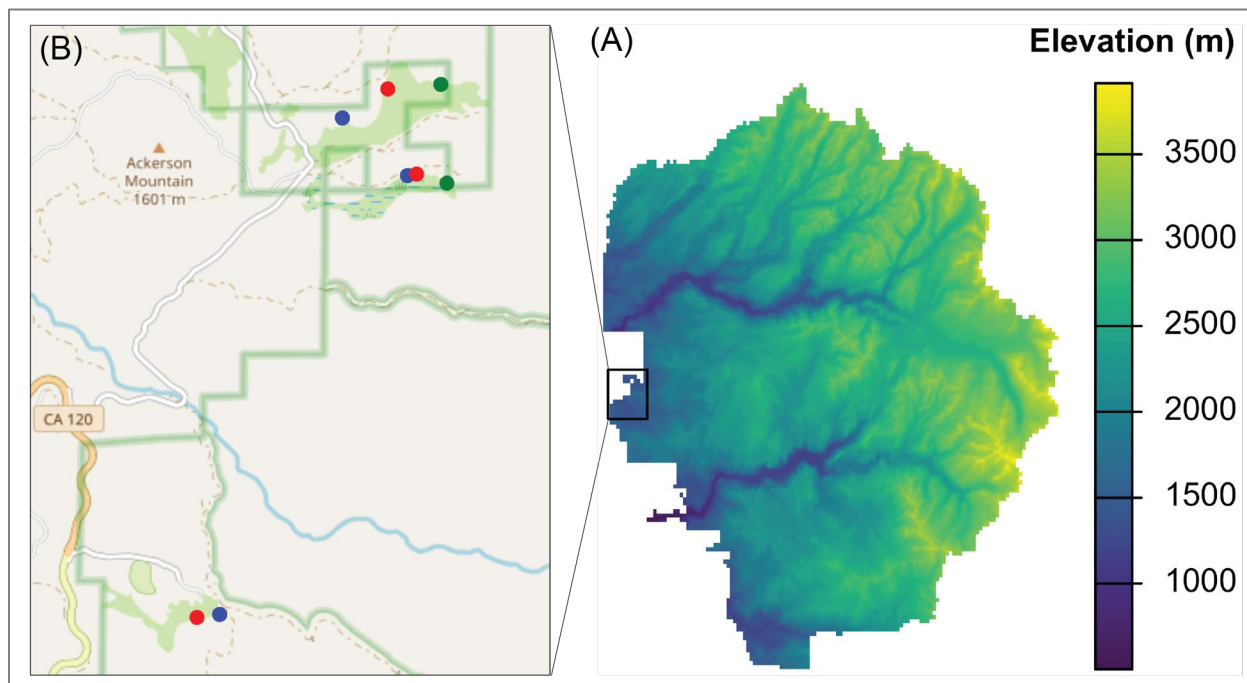


Figure 1. Great gray owl prey regional context and sampling locations. (A) Yosemite National Park, showing the Park elevation and the position of Ackerson and Hodgdon Meadows in the box. (B) Sampling localities within Ackerson Main, Ackerson South, and Hodgdon Meadow. Blue points show 2023 sampling localities, red points show the early 2024 sampling localities, and green points show the late 2024 sampling localities (no Hodgdon Meadow sampling for this period).

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Two nearby meadows, Ackerson Meadow South (part of the Ackerson Meadow complex, hereafter called Ackerson South) and Hodgdon Meadow, are similar sizes and at similar elevations to Ackerson Main (Figure 1). Ackerson South is hydrologically connected to the larger Ackerson Main meadow, but it has been relatively less altered by prior human impacts, with much of the meadow remaining wet or fully saturated for much of the year prior to restoration (Ackerson Meadow Restoration Environmental Assessment 2021). In contrast to the Ackerson Meadow complex, Hodgdon Meadow has been managed by Yosemite National Park since 1890 and did not experience as intense of grazing and agricultural impacts as Ackerson Main Meadow. Hodgdon Meadow and Ackerson South thus represent different versions of the intended future condition for Ackerson Main after restoration and can be used as comparisons for changes in prey availability in Ackerson Main.

Overall, there is a clear need to identify the spatial distribution, abundance, and habitat associations of great gray owl prey (focusing on voles and pocket gophers) in Ackerson Main prior to and during the early stages of meadow restoration, in order to ensure habitat management projects do not have inadvertent negative impacts on prey species and therefore great gray owls. Given the paucity of data on great gray owl prey, targeted efforts focused on assessing prey populations of the Ackerson Main meadow, using nearby Ackerson South and Hodgdon Meadow as reference sites (Figure 1), will build on the earlier survey efforts of Kalinowski et al. (2014) and provide baseline data for prey populations, so that park managers can monitor the effects of meadow restoration on prey in the future. However, traditional efforts to assess prey populations are quite resource intensive, especially live-trapping efforts. Thus, many indirect measures of prey activity are used, such as gopher activity surveys and vole runway surveys, but for voles especially, these may be unreliable in part because runways are not reliably visible for all vole species (e.g., *Microtus longicaudus*; Smolen and Keller 1987). Recent work primarily in agricultural settings has shown that chew blocks (small, non-toxic wax blocks infused with bait) provide useful indices of relative abundance change through time for vole populations (Engeman et al. 2016; Whisson et al. 2005), but the extent to which chew blocks translate to wild settings is unclear.

Thus, there were four primary project objectives for this inventory:

Objective 1: Provide baseline data on great gray owl prey populations (presence and/or abundance) at Ackerson Main, Ackerson South, and Hodgdon Meadow.

Objective 2: Provide a preliminary assessment of whether the presence and/or abundance of great gray owl prey (primarily gophers and voles) varies by habitat (forest or meadow), by site, and across years.

Objective 3: Provide a preliminary assessment of whether small mammal presence and/or abundance is related to vegetation or soil properties.

Objective 4: Explore the suitability of chew blocks for assessing abundance change in great gray owl prey through time.

Methods

Study Design

Overall

Surveys were conducted within Yosemite National Park boundaries in non-wilderness areas, with permission from the park (Study # YOSE-00958 to JL Blois). We conducted surveys in and adjacent to three areas: Ackerson Main (the primary target of restoration), and Ackerson South and Hodgdon Meadow (reference sites) (Figure 1). The inventory occurred during the great gray owl breeding season, April–August, which is a critical period for documenting the availability of great gray owl prey. This period is also the most relevant to owl management since it is when individuals have the highest energetic demands and when owls may be the most dependent on Ackerson Meadow. Overall, we surveyed prey at three time periods: early season (late May, early June) in 2024 and late season (late July, early August) in 2023 and 2024 (Table 1).

Table 1. Sampling overview showing the site, grid habitat, year, period, specific sampling week, and details for the mammal and vegetation surveys. For vegetation plots, we indicate the number that were placed at each site/grid. For live traps, chew blocks, and camera traps, we indicate whether a site/grid was sampled for each (Y = yes; N = no). We also indicate whether each site/grid was sampled for gophers, but provide additional details on gopher effort (the number of belts placed at each site/grid). More detailed estimates of sampling effort for live traps, chew blocks, and camera traps are provided in the appendix.

Site	Grid	Year	Period	Sampling Week	Vegetation (# Plots)	Live Traps	Chew Blocks	Cameras	Gophers	Gophers (# Belts)
Ackerson Main	Forest	2023	Late	August 7–11, 2023	16	Y	Y	N	Y	2
	Meadow	2023	Late	August 7–11, 2023	16	Y	Y	N	Y	2
	Central	2023	Late	August 7–11, 2023	16	Y	Y	N	Y	2
	Forest	2024	Early	May 27–31, 2024	8	Y	Y	Y	Y	2
	Meadow	2024	Early	May 27–31, 2024	8	Y	Y	Y	Y	2
	Forest	2024	Late	July 22–26, 2024	8	Y	Y	Y	Y	2
	Meadow	2024	Late	July 22–26, 2024	8	Y	Y	Y	Y	2
Ackerson South	Forest	2023	Late	July 31–August 4, 2023	18	Y	Y	N	Y	1
	Meadow	2023	Late	July 31–August 4, 2023	6	Y	N	N	N	0
	Forest	2024	Early	June 3–7, 2024	8	Y	Y	Y	Y	2
	Meadow	2024	Early	June 3–7, 2024	8	Y	Y	Y	Y	1
	Forest	2024	Late	July 15–19, 2024	8	Y	Y	Y	Y	2
	Meadow	2024	Late	July 15–19, 2024	8	Y	Y	Y	Y	1
Hodgdon	Forest	2023	Late	August 7–11, 2023	20	Y	Y	N	Y	2
	Meadow	2023	Late	August 7–11, 2023	16	Y	Y	N	N	0
	Forest	2024	Early	June 3–7, 2024	8	Y	Y	Y	Y	2
	Meadow	2024	Early	June 3–7, 2024	8	Y	Y	Y	Y	1

Great gray owls nest in trees near meadows and the distance they forage from the nest is limited during the breeding season (van Riper and van Wagtendonk 2006), so we focused survey efforts on meadow edges. To determine specific sites for sampling, we used GIS to outline the meadow edge at all three locations, then randomly sampled a site location along the meadow edge with the following constraints: all sites were in non-wilderness locations and the random locations of all sites across sampling periods were at least 100 m away from one another (though due to how the grids were laid out around the random point and meadow size constraints, in some cases the specific grid locations were very close to one another in 2023 vs. 2024).

Within each site, we surveyed the small mammal prey community at two positions centered on the forest/meadow boundary: within the meadow close to the forest edge and within the forest close to the meadow edge. Grids were typically a minimum of 50 m away from one another. At each site, we paired the live trapping grids with chew block grids, and completed gopher and vegetation surveys. Figure 2 illustrates the basic sampling layout at a site, though slight variations occurred across years and sites (documented in field notes and through effort corrections; Table 1). Our focus was on two groups of great gray owl prey, voles (*Microtus* spp.) and gophers (*Thomomys* spp.), but our sampling scheme captured small mammals more broadly (any member of the orders Rodentia and Eulipotyphla).

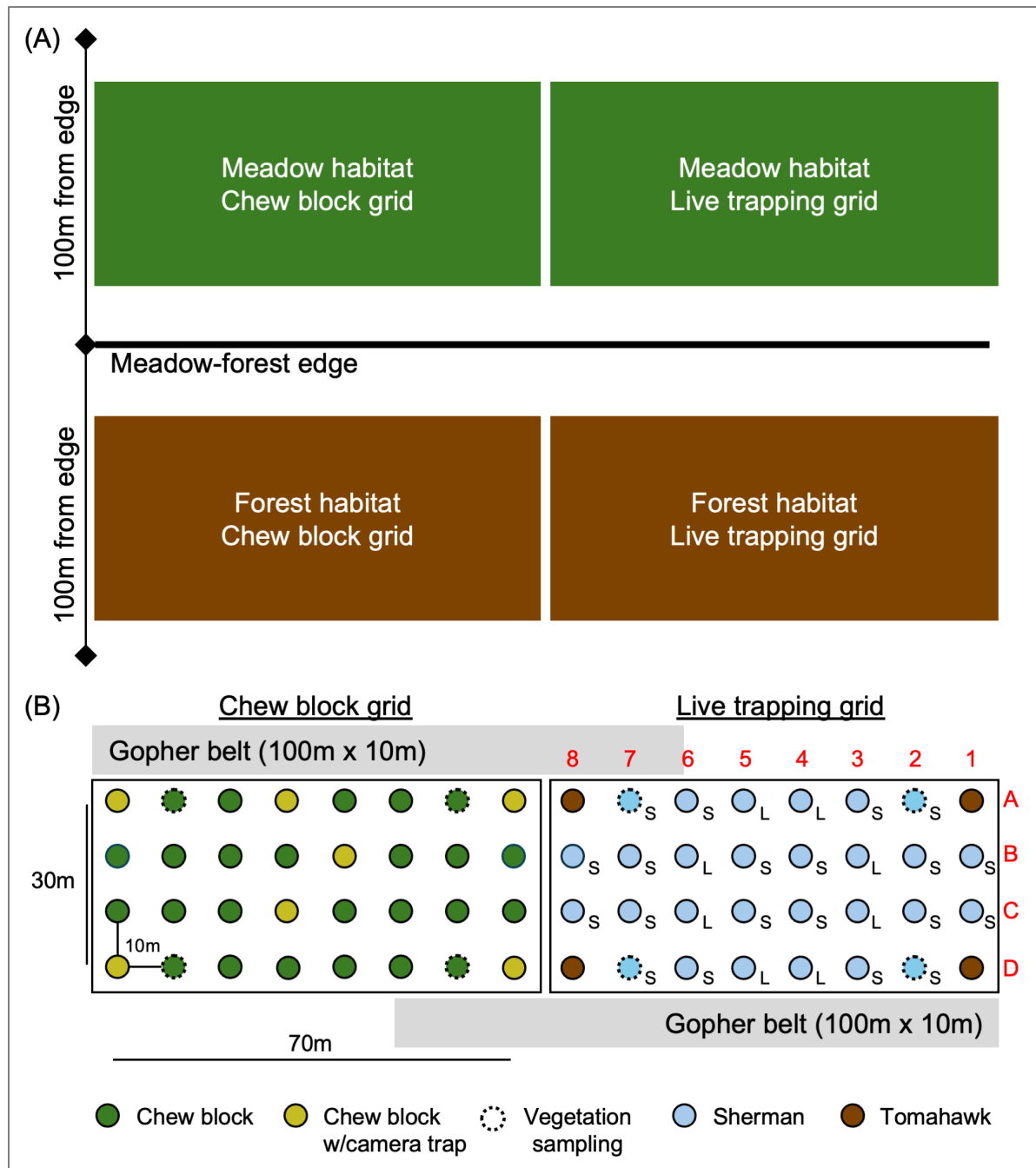


Figure 2. Primary study design for the Ackerson great gray owl prey project. (A) Two primary habitats were sampled—a meadow habitat and a forest habitat, both within 100 m of the meadow-forest edge. (B) Within each habitat, four types of surveys were completed: live animal surveys in the live trapping grid, chew block and camera trapping in the chew block grid, gopher activity surveys within flanking gopher belts, and vegetation surveys at a subset of locations within the live trapping and chew block grids. Note that variations to this primary design occurred occasionally at some locations or times, as documented in the method, field notes, and the sampling effort tables (Table 1; Appendix). L indicates large Sherman traps and S indicates small Sherman traps.

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Live Trapping Grids

We used a survey grid to sample the small mammal community at each site. Each grid was roughly 70 m × 30 m: four lines were parallel to the meadow/forest edge, with 8 traps along each line spaced 10 m apart, for a total of 32 live traps (4 Tomahawk and 28 Sherman traps). The four lines were 10 m apart from one another. Tomahawk traps were set at the four corners, and we alternated small and medium sized Sherman traps at the rest of the grid positions (Figure 2; Appendix). In 2023, the Ackerson South site was very wet and so the trapping effort differed from other locations. Specifically, the forest grid was 60 m × 40 m: 7 lines parallel to the meadow/forest edge, with 5 traps on each line spaced 10 m apart, for a total of 35 live traps (5 Tomahawk and 30 large and small Sherman traps, with Tomahawks at the four corners and the center of the grid). Because the extremely wet meadow prohibited safe placement of most traps, the meadow grid was shifted towards the forest edge as far as possible and was abbreviated; two full trapping lines (5 traps each line) were placed on more secure ground at the meadow edge and two abbreviated lines were placed in the wet meadow. Placement of additional lines deeper into the meadow and most traps on the two abbreviated lines was not possible without risking animal safety.

Grids were typically deployed for four nights, Monday evening through Friday morning, with live traps open overnight (see Appendix for total effort per grid). We baited traps with a mix of oats, bird seed, and peanut butter, supplemented with meal worm for shrews. No pre-baiting occurred prior to initial opening of the traps. Traps were opened by ~6 pm each day (prior to sunset) and checked by ~9:30 am each morning and closed for the day. We tallied the total number of live trap nights per sampling grid as the total number of nights a trap was operational, summed across all traps at the grid. Any animal in a trap was typically identified, sexed, weighed (g), and measured (total length, tail length, ear length, hindfoot length, in mm). An ear snip and hair sample was taken for most specimens and then the live animal was released. All live trapping was done following American Society of Mammalogists guidelines (Sikes and the Animal Care and Use Committee of the American Society of Mammalogists 2016) under the supervision of the UC Merced IACUC, Study # 2023-1146, with CA Scientific Collecting Permit # S-230460001-23054-001 to JL Blois.

Chew Block and Camera Trap Grids

Chew block grids were the same size as the live trapping grids: a 70 m × 30 m grid, with four lines parallel to the meadow/forest edge, with 8 baits on each line spaced 10 m apart, for a total of 32 chew block baits (Figure 2). We placed a ~20 g No-Tox Mini Block (LiphaTech Product No. 80000663) at each grid position, resting on top of a small plastic platform (Figure 3). To gain information about the identity of the animals eating the chew blocks, we placed camera traps at a subset of grid positions (GardePro Trail Camera Model T5CF). Cameras had the following settings for most sampling periods: 16 MB photos, photo burst of 2 pictures, a detection delay of 20 s, PIR (passive infrared) sensitivity set at low. PIR was set to medium for some of the cameras at the first site sampled in 2024, then changed to low for all subsequent camera trapping bouts to help reduce the number of inadvertent camera images due to movement of the vegetation surrounding a camera.



Figure 3. The chew block and camera trap setup. Chew blocks were placed on a white plastic plate, with or without a camera. Cameras were placed at a subset of chew block stations where they were attached to a rebar stake fixed into the ground, ~12–18 inches above the ground, with the lens pointed downward directly at the chew block. A clear plexiglass plate was affixed to the rebar stake to funnel animals into the camera view and temporarily hold back vegetation from interfering with the camera view.

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Due to purchasing delays, we only placed camera traps in the 2024 sampling periods. In the first round of camera trap deployment, at one site (Ackerson Main in June 2024) we moved the camera to a new grid position if the chew block was completely removed from the grid position at any point in the week. However, for all subsequent surveys, we kept all cameras fixed at their original grid positions as shown in Figure 2. We aimed for one camera per primary grid line, with the additional three cameras added to cover as much of the chew block grid area as possible. In all cases, we tallied the total number of “camera trap nights” as the total number of nights a camera was operational, summed across all cameras on a grid, to account for slight differences in number of cameras deployed, dates of deployment, etc. (see Appendix for total effort per grid). We examined all images to determine whether an animal was detected in the image, and if so, what species the animal likely

belonged to. We identified all animals to the best taxonomic level possible, though we generally identified small mammals to genus due to uncertainty in identification based on images. In some cases of blurry or obscured animal images, we used contextual information for the images (such as vole images from the photos captured immediately before or after the focal image) to help refine our identification.

Gopher Activity Surveys

We performed gopher surveys in 100 m × 10 m survey belts flanking the primary survey grids, following methods used by Kalinowski et al. (2014; see Table 1 for total number of gopher belts per site). Gophers were surveyed indirectly by walking the belt, typically on Day 2 of the survey period, noting the location of and smoothing over any potential signs of gopher activity. On the following day and any subsequent days as necessary, belts were walked and observed for signs of new soil disturbance, indicating active gophers. Once an active observation was made during a survey, subsequent observations were recorded as unique individuals only if fresh activity at least 10 cm distant was noted. Belts were walked each day throughout the survey period until fresh activity was noted; all signs of gopher activity within the belt were recorded on that day and then the survey ended for the week.

Vegetation

We also examined vegetation via a minimum of four plots spread around each grid. Vegetation plot locations were initially chosen to cover the breadth of a grid, with the added constraint of avoiding a camera location on the chew block grid, and were fixed across all surveys. In 2023, we sampled most grids at 8 plots, but reduced effort to four plots per grid for 2024 because the lower number was adequate to characterize vegetation in the grid. For each vegetation plot, we used a $\sim 51 \times 51$ cm quadrat (0.2601 m^2 per plot) that was gridded into 36 subsections, each $\sim 8.5 \text{ cm} \times 8.5 \text{ cm}$, with 25 internal intersections at the corners of each subsection (Figure 4). For each quadrat, we determined the maximum vegetation height, vegetation cover, stem density, the presence or absence of different categories of plants within the quadrat, and soil wetness. We measured maximum vegetation height as the maximum height (cm) attained by any plant found within the quadrat; vegetation cover was measured as the proportion of internal intersections (of a total of 25) that were directly above non-bare ground; stem density was measured as the total number of individual stems rooted within one subsection of the quadrat, typically situated at the NE corner of the plot; and presence/absence was assessed for Sedge, Grass, Rush, Forb, Shrub, and Trees. Soil wetness was measured at the center of the quadrat in two ways: via assessment of categorical wetness (following Kalinowski et al. 2014, p. 550: “dry when no moisture other than morning dew was detected, moist when soil was wet enough to clump and stick to fingers, saturated when water bubbled up when soil was depressed with fingers, and flooded when water was present above the soil surface”), and using a soil moisture meter (HoldAll, Model 60182L) to get a numeric moisture assessment (discrete values ranged from 0, dry, to 10, wet). For all numeric variables (maximum vegetation height, vegetation cover, stem density, and quantitative soil wetness) we calculated the mean value for the grid based on all vegetation plots within the grid, and for the categorical variables (presence/absence of Sedge, Grass, Rush, Forb, Shrub, Tree; qualitative soil wetness) we calculated the modal value within the grid.



Figure 4. The vegetation sampling quadrat.
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Analyses

All analyses were done in R (version 4.4.1 (2024-06-14), R Core Team 2025) with R Studio (version 2024.09.0+375, Posit team 2024), using the following packages: ggpmisc (Aphalo 2025), ggpubr (Kassambara 2025), MVN (Korkmaz et al. 2014), patchwork (Pedersen 2025), purrr (Wickham and Henry 2023), readxl (Wickham and Bryan 2023), rstatix (Kassambara 2023), stringr (Wickham 2023), and tidyverse (Wickham et al. 2019).

Objective 1: Baseline Data on Great Gray Owl Prey Abundance

We determined a variety of proxy measures for relative abundance of great gray owl prey based on the different animal sensing methods; all estimates are imperfect proxies for true abundance. Abundance estimates were typically weighted by effort (total number of trap nights; see Appendix for the specific effort associated with each grid). For the gopher activity estimates, where sampling was relatively standardized across survey methods, we simply averaged estimates across the number of gopher belts associated with a grid.

Live Trapping

Live-Trapped Vole Abundance

We measured vole abundance for each live trapping grid for each sampling period. Vole abundances were highly variable, and estimating recaptures was inconsistent because some animals escaped handling before measurements and ear snips could be taken (which were also used to mark individuals). Thus, we estimated vole abundance in two ways that capture the range of possible abundances: 1) Minimum number of individuals (MNI), which is the maximum number of individuals caught in a single day within the trapping period for a grid, and 2) Maximum number of individuals (max), which is the sum of all individuals caught over the course of the trapping period for a grid. In each case, we weighted the abundance estimate by total trapping effort, to account for differences in effort across grids. For some analyses, we also collapsed vole data to presence/absence data per grid for a sampling period, based on whether at least one vole was observed in the live trapping grid.

We compared the two estimates of vole abundance using Spearman's rho, because the bivariate distribution of the datasets was not normal due to the large number of zeros (based on the Henze-Zirkler test for multivariate normality). Almost every vole we captured and assigned to a species was identified as *Microtus montanus*. One individual was identified in the field as *Microtus* sp. (caught in our first sample in August 2023) and was likely *Microtus montanus*; we thus considered this individual as belonging to *Microtus montanus* in the abundance tallies.

Species Richness

We calculated species richness for each live-trapping grid and each chew-block grid as the total number of species found in each grid based on their detection in either live traps or camera traps. We restricted estimates of species richness to taxa in Orders Rodentia and Eulipotyphla, since both live and camera traps were designed to capture small mammals. We also assumed that any individual identified tentatively to a particular species (e.g., individuals with "cf." in their taxonomic name [in the full dataset](#); NPS 2026) was definitely that species, for the purposes of calculating species richness.

Gophers

We estimated gopher abundance based on the activity surveys, following Kalinowski et al. (2014), by counting the number of unique observations of gopher activity per gopher belt. In most cases, multiple gopher belts were surveyed per grid (two each for the live trap and chew block grids, though see Table 1 for specific effort associated with gopher surveys), so we calculated the mean gopher activity per site, grid position, year, and sampling period.

Chew Blocks

For each grid during a single sampling period, we calculated the mean amount (grams) of chew block material removed and used this as a proxy for total animal activity/abundance on the grid (Engeman et al. 2016). We did not individually weigh each chew block prior to deployment. Instead, we measured 10 chew blocks that were not deployed to estimate the mean ($\pm$ sd) chew block weight before deployment. After recovery, we weighed each chew block individually, estimated the amount

of material removed for each individual chew block, then calculated the mean amount of material for each sampling grid. For some analyses, we also converted the mean amount of chew block material removed to a presence-absence estimate of vole activity, based on the relationship between chew block material and presence of live or camera-trapped voles. We set the threshold pragmatically, as the minimum amount of chew block material removed that was associated with at least one camera-based or live vole observation.

Camera Trap Observations

For each chew block grid, we also estimated vole (*Microtus* spp.) abundance based on the number of camera images captured for voles per grid; this is more accurately a measure of vole activity, but may be a proxy for vole abundance. We focus on vole abundance because vole observations constituted the vast majority of our camera images (see Results). We calculated two measures: 1) the raw number of vole images per grid and 2) a measure that captures the number of activity “bursts” (sets of images that are of the same individual in sequence), using an interval of 60 s of no vole detections to delineate different activity bursts. We then weighted the two activity estimates by the total number of camera trap nights to account for differences in effort per grid. For some analyses, we also collapsed the vole camera abundance estimates to presence/absence data, based on whether at least one vole was observed in any of the images for a grid per sampling period. We did not observe any gophers on the cameras, so we only calculated activity estimates for voles. We compared the two camera-based estimates of vole abundance using Spearman’s rho, because the bivariate distribution of the datasets was not normal due to the large number of zeros (based on the Henze-Zirkler test for multivariate normality).

Normality Tests

Following calculation of abundance proxies and species richness estimates, we assessed the normality of each dataset visually using a histogram and qqplot, and statistically using a Shapiro-Wilk test. None of the original animal datasets were normally distributed, in most cases due to the very large number of zero values. Some, but not all, of the continuous vegetation and soil variables were normally distributed. There was no practical way to transform these data, so we 1) relied on non-parametric tests for many analyses or 2) transformed abundance estimates to simple presence/absence data for analyses that did not have an assumption of normality.

We detail the specific comparative statistical tests we used in each objective below. In all cases, we used a threshold of $p < 0.05$ as our cutoff for assessing the significance of statistical tests.

Objective 2: Does the Abundance of Gophers and Voles Vary by Habitat, by Site, and Across Years?

In total, we have 3 primary proxies for abundance of voles (maximum abundance of live-trapped voles per grid, mean amount of chew block removed per grid, and raw number of vole camera images per grid) and one proxy for the abundance of gophers (mean gopher activity per grid). For each proxy, we examined whether abundance differed by site (Ackerson Main, Ackerson South, Hodgdon), by year (2023 vs. 2024), and by grid (which is equivalent to habitat type: forest or meadow), using a Wilcoxon sign-rank test (for two group comparisons: habitat type and year) or a

Kruskal-Wallis test (for site comparisons with >2 groups). We also grouped data across years and examined whether great gray owl prey abundance differed across both sites and habitat types, though sample size was extremely small in some cases so these results should be interpreted with caution.

As part of our exploratory analyses, we examined whether there was a tradeoff between voles vs. gophers (using Pearson's correlation because these data were bivariate normal, per the Henze-Zirkler test for multivariate normality). We also tested whether species richness varied across sites, years, or grid habitats using a Wilcoxon sign-rank test (for two group comparisons: habitat type and year) or a Kruskal-Wallis test (for site comparisons with >2 groups).

Objective 3: Is Great Gray Owl Prey Abundance Related to Vegetation or Soil Properties?

We examined the relationship between the presence or absence of great gray owl prey and vegetation/soil properties using multiple logistic regression. We developed a full model that included as predictor variables the four quantitative vegetation/soil variables (maximum vegetation height, vegetation cover, stem density, and soil wetness) as well as the presence or absence of the 6 different types of vegetation (Grass, Shrub, Sedge, Rush, Tree, Forb), removing any variable that was either invariant or strongly (>0.7) covarying with another variable. We also built a null model that included only the intercept. Because the null model was in all cases substantially better than the full model, we then built a set of candidate models to compare against the null model. Two candidate models included only the quantitative or the categorical variables. We also developed simple single variable models for all variables. We then used AICc to determine whether any of the candidate models were better than the null model. If so, we then sequentially added variables to the top model to determine whether a multivariable model improved upon the top model (including all variables within $\Delta AICc < 2$) or was better than the null model. In this way, we determined a final "best" model that predicted the presence or absence of great gray owl prey. We followed this procedure for four different proxies for great gray owl prey: presence or absence of voles based on live traps, camera traps, or chew blocks, and presence or absence of gophers.

Objective 4: Are Chew Blocks Suitable for Assessing Abundance in Great Gray Owl Prey?

In Objective 2, we assume that chew blocks are a proxy for vole abundance following Engeman et al. (2016) and Whisson et al. (2005). Here, we examine this assumption in more depth. For each site, we usually had two paired grids; the forest live trapping grid and chew block grid and the meadow live trapping grid and chew block grid. Within the chew block grids, we also deployed cameras at a subset of chew blocks in 2024. Thus, to test which species may be responsible for removing chew block material, we examined the relationship between several different proxies within and across the paired grids. Specifically, we examined vole abundance estimated from live trapping and vole activity from the camera traps with the amount of chew block removed, based on site and grid position for each trapping period, via Spearman's rho because the bivariate normal distribution of the datasets was not normal due to the large number of zeros (based on the Henze-Zirkler test for multivariate normality). We also compared the mean amount of chew block material removed with gopher activity, as well as small mammal species richness assessed via both live trapping and camera traps, via a Spearman's rho test, to test whether non-vole measures better correlate with the amount of chew block material removed on a grid.

Results

Overall Trapping Results

We sampled the meadows three times over the course of 2023–2024: August 2023 (all three sites, no cameras), late May–early June 2024 (all three sites), and late July 2024 (Ackerson Meadow sites only). Various issues arose in the course of field work that caused effort to differ slightly among sites. For example, the Ackerson South meadow was completely saturated with deep water in 2023, and setting live traps or chew blocks was impossible within most of the meadow grid; we thus primarily sampled in the forest and placed an incomplete live-trapping grid at the meadow edge (but no chew block grid). In some cases, individual traps were damaged or cameras were moved to a new location within a grid. We detail the specific great gray owl proxies measured at each site as well as the gopher activity effort (number of belts) in Table 1, and the total effort per site for each vole proxy type (live traps, chew blocks, camera traps) in the Appendix.

Abundance Estimates

Vole Live-Trapping Abundance

The two measures of vole abundance based on live trapping were highly correlated with one another ($\rho = 1$, $p < 0.001$; Appendix), so we only report further results based on maximum live-trapped vole abundance estimates. Vole abundance did not vary statistically among sites or years (Figure 5), likely due to low sample size and many zeros in the dataset. We did not find any voles at Hodgdon Meadow in our live trapping efforts across the two years. Voles (*Microtus montanus*) were found at both Ackerson sites, though they tended to be more abundant at the Ackerson South meadow (Figure 5a). Across sites and years, voles were only found in the meadow grids and vole abundance was significantly greater ($W = 16$, $p = 0.0325$) in meadow grids than the forest grids (Figure 5c). There were no significant differences in vole abundance when separated by both site and grid habitat (Appendix).

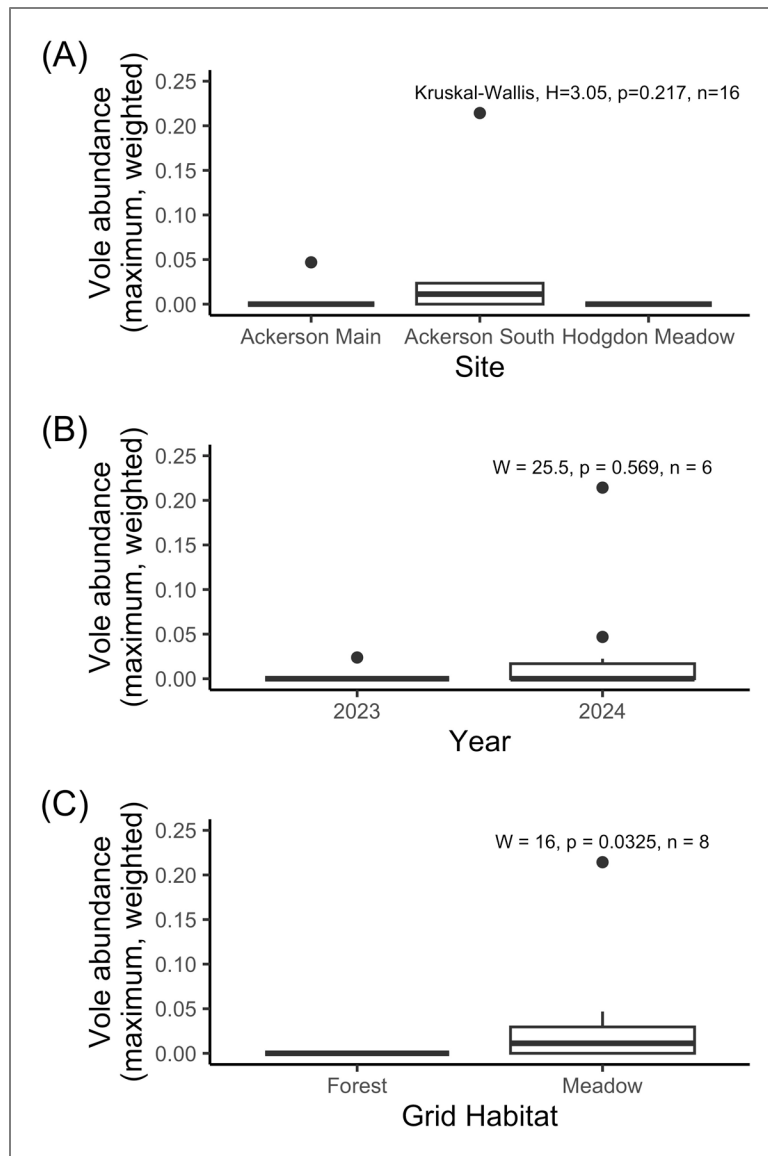


Figure 5. Montane vole (*Microtus montanus*) abundance across sites, years, and habitats. Vole abundance is based on the maximum abundance of voles observed during live trapping, weighted by sampling effort. (A) Voles were found at both Ackerson sites, but not at Hodgdon Meadow, though there were no significant differences in abundance among sites. (B) There were no significant differences among years in vole abundance, though voles tended to be more abundant in 2024 vs. 2023. (C) Voles were significantly more abundant in the meadow grids and were not detected in the forest grids.

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Gopher Activity Data

Gopher activity was detected at all three sites, in both years, and in both the meadow and forest grid habitats (Figure 6). However, there were no significant differences in gopher activity among sites, years, or habitats, though there tended to be more gopher activity at Ackerson Main than the other two sites, and anecdotally, all meadow grid gopher activity was observed on the forest edge of the

grid. There were no significant differences in gopher activity when separated by both site and grid habitat (Appendix).

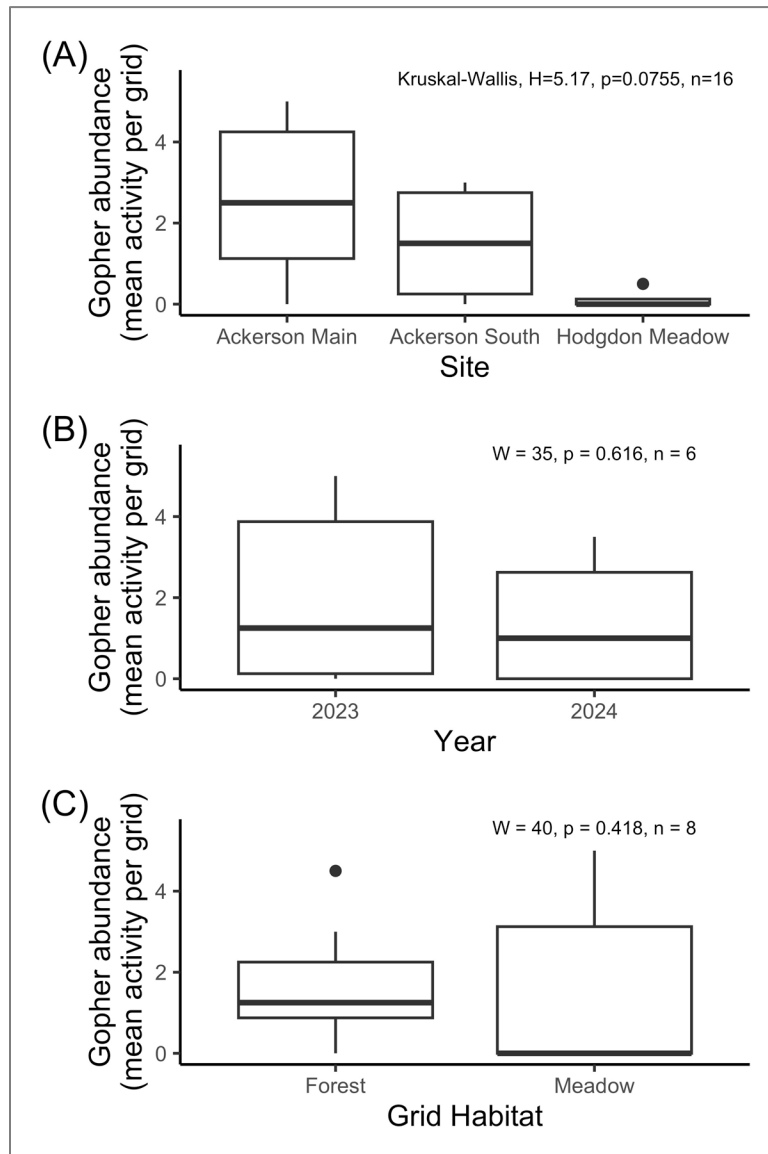


Figure 6. Gopher activity estimates across (A) sites, (B) years, and (C) grid habitats. There were no significant differences in gopher activity among sites, years, or grid habitats, though gophers tended to be more active/abundant at Ackerson Main than the other two sites.

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Chew Block Data

Chew blocks were deployed in both sampling years. There was significantly more ($H = 8.56$, $p = 0.0139$) chew block material removed in the Ackerson South grids than at the other two sites (Figure 7). There were no significant differences in the amount of chew block material removed among years or among grid habitats, though there was a trend towards more chew block removal in

2024 and in the meadow grids than the forest grids (Figure 7). There were no significant differences in chew block material removal when separated by both site and grid habitat (Appendix).

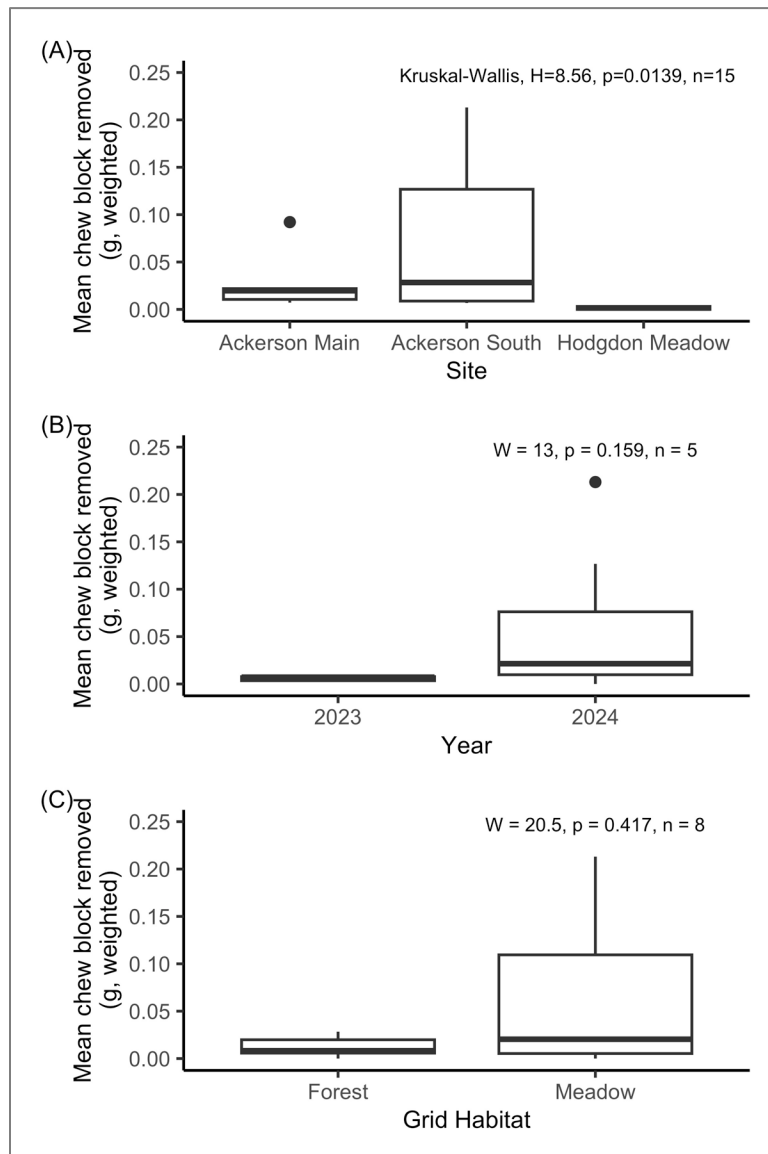


Figure 7. Mean amount of chew block removed across (A) sites, (B) years, and (C) grid habitats. There was significantly more chew block material removed at the Ackerson South site than the other two sites, but no significant differences among years or grid habitats.

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Camera Trapping Data

Camera traps were only deployed in 2024. Overall, 3,943 images captured a small mammal individual; of these, 3,909 were classified as *Microtus* spp. The additional small mammal taxa captured were *Peromyscus* spp. (33 images) and *Neotamias* sp. (one image). We also detected three species within Order Carnivora: *Mustela erminea* (8 images), *Mephitis mephitis* (6 images), and

Urocyon cinereoargenteus (7 images), as well as various non-mammals that were only coarsely identified (e.g., Lepidoptera, Insecta). The two measures of vole activity based on camera images were highly correlated with one another (Appendix; $\rho = 0.9862$, $p < 0.0001$), so we only report further results based on the number of raw vole camera images. Overall, there were no significant differences in vole activity among sites or habitats (Figure 8), and there were no significant differences in vole activity sensed by the cameras when separated by both site and grid habitat (Appendix). Vole activity was detected on the cameras only at Ackerson Main and Ackerson South, and the vast majority of observations occurred in the meadow grid habitats (Figure 8). Only five camera images of a vole (out of 3,909 total) were detected in a forest grid: one image at Ackerson South and five images at Ackerson Main, in both cases at cameras that were placed on the meadow edge of the forest grid.

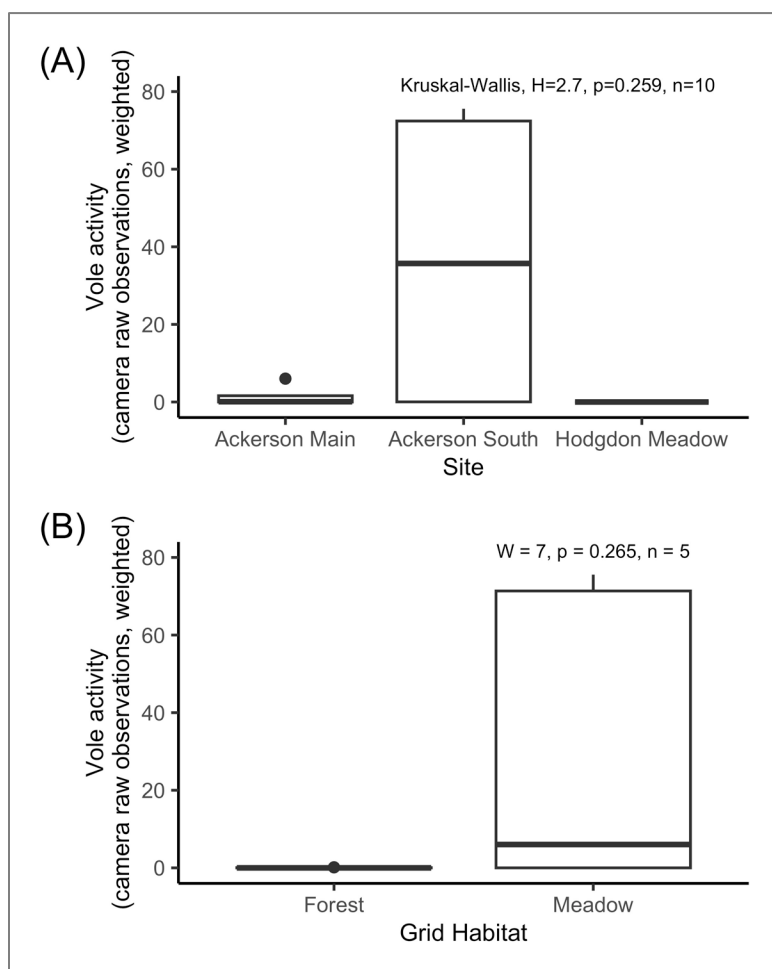


Figure 8. Vole activity estimates across (A) sites and (B) grid habitats, estimated via the total number of camera observations (weighted by effort). There were no significant differences in vole activity among sites or grid habitats, though voles tended to be observed more at Ackerson South than the other two sites and the vast majority of the vole activity was in meadow grids rather than forest grids.

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Concordance Among Different Great Gray Owl Prey Abundance Proxies

Vole abundance estimated via live trapping was significantly positively correlated with the number of raw camera observations of voles on the adjacent chew block grid ($\rho = 0.811$, $p = 0.0147$; Figure 9). There was also a significant correlation between the amount of chew block removed and live vole abundance on the adjacent live-trapping grid ($\rho = 0.685$, $p = 0.0049$) and between the amount of chew block removed and camera vole activity within a grid ($\rho = 0.952$, $p = 0.0003$; Figure 10).

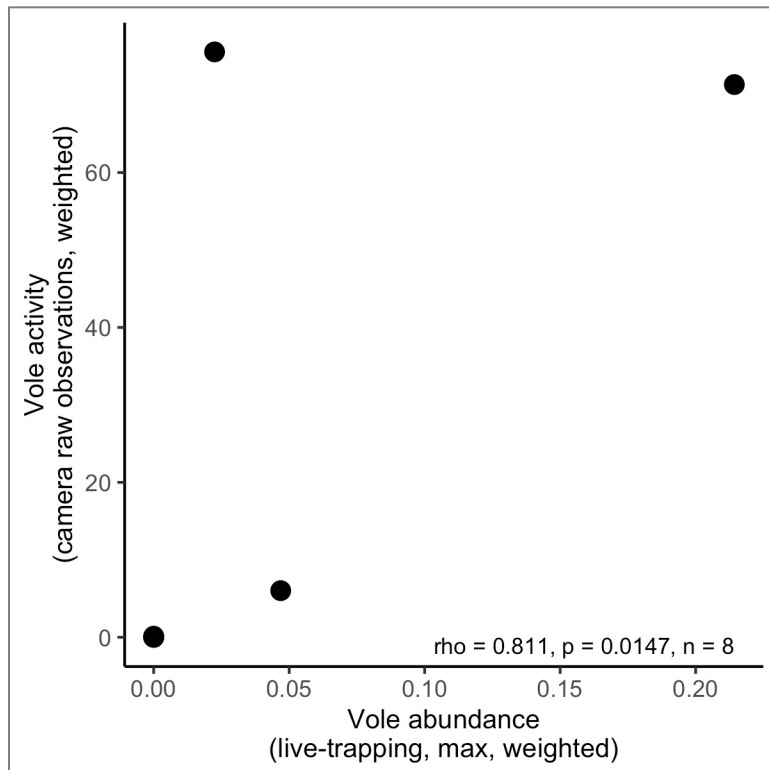


Figure 9. Vole (*Microtus montanus*) abundance estimated via live trapping was significantly correlated with the number of raw observations of voles (*Microtus* spp.) from cameras on the adjacent chew block grid.

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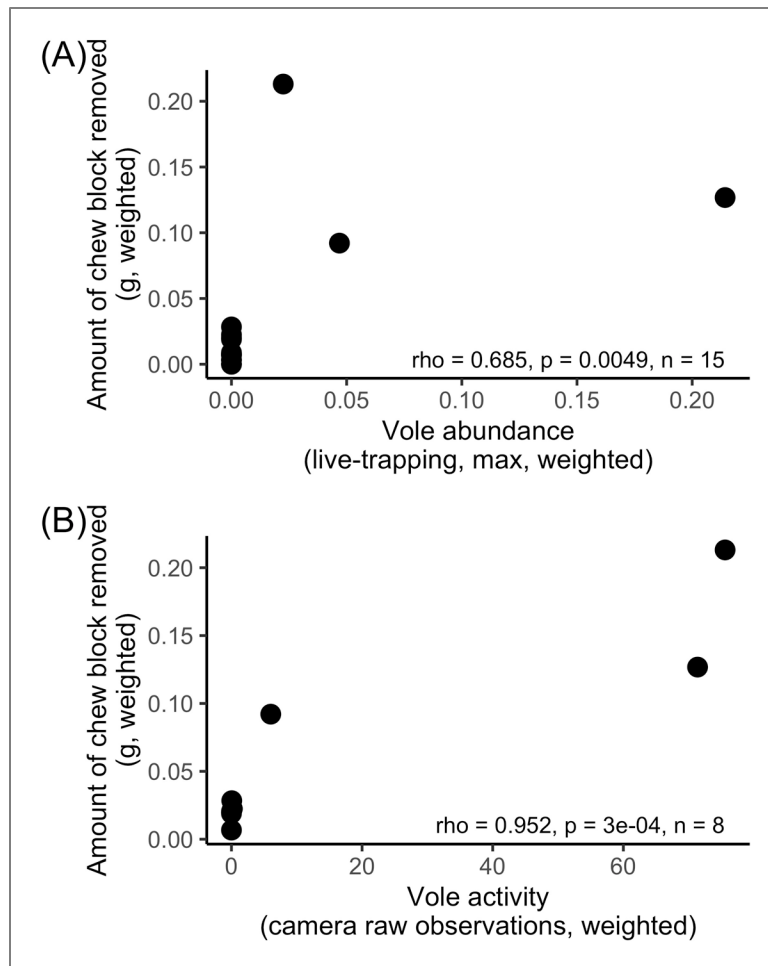


Figure 10. The amount of chew block material removed (weighted) was significantly positively correlated with two different estimates of vole abundance. (A) Relationship between the amount (grams, g) of chew block material removed (weighted by effort) and vole (*Microtus montanus*) abundance assessed via live trapping (maximum abundance, weighted). (B) Relationship between the amount (grams, g) of chew block material removed (weighted by effort) and vole (*Microtus* spp.) activity assessed via camera traps (raw number of camera observations, weighted).

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The amount of chew block material removed was not significantly associated with gopher activity or species richness detected via live trapping (Appendix). There was a positive correlation between the amount of chew block material removed and species richness detected via the camera traps ($\rho = 0.694$, $p = 0.026$), but there was no correlation between vole abundance (estimated via live trapping) and gopher activity across grids (Appendix).

Species Diversity Results

Across all sites, we captured a maximum of 3 small mammal species at a single grid (Ackerson South, Forest, 2024, late) and 5 small mammal species at a single site (Ackerson South, 2024, late), based on live-trapping data. We captured a similar level of diversity with the camera traps: a maximum of 3 species at a single grid (Ackerson Main, Forest, 2024, late) and 3 species at a single

site (Ackerson Main, 2024, late). Note we did not distinguish among species within the camera images and instead identified all images to the genus level, which accounts for the slightly lower site-level differences between live-trapping and camera trapping.

There was no significant correlation between species richness detected from cameras versus live trapping (Appendix). There were no significant differences in species richness across sites, years, or grid habitat based on live-trapping data or on camera trap data (Appendix).

Relationship Between Great Gray Owl Prey, Vegetation and Soil

A final model was settled on for all four of the great gray owl prey proxies (Table 2). In some cases, several models were within two AICc units of one another, indicating that multiple variables were potentially influencing great gray owl prey presence. In the case of gopher presence/absence, none of the biological models were significantly better than a null model that included only the intercept. For all proxies, soil wetness appeared in at least one of the top models. It was positively associated with vole presence and negatively associated with gopher presence (Table 2).

Table 2. Overview of final fitted models of the relationship between the proxy for great gray owl prey presence and vegetation/soil variables. For each model, we show the model name (with the direction of the relationship with the proxy for each variable: “+” = positive, “-” = negative), and model fit parameters including the number of parameters (K, includes the intercept), Akaike’s Information Criterion, corrected for small sample size (AICc), the change in AICc for each subsequent model (Δ AICc), the relative model likelihood (ModelLik), AICc weights or model probabilities (AICcWt), and the log likelihood (LL).

Proxy	Model Name	K	AICc	Δ AICc	ModelLik	AICcWt	LL
Vole (live traps)	Vegetation Cover (+)	2	16.0134	0	1.0000	0.3372	-5.5452
	Wetness (+)	2	16.9464	0.933	0.6272	0.2115	-6.0117
	Combined (Vegetation Cover (+), Wetness (+))	3	16.974	0.9606	0.6186	0.2086	-4.487
Vole (chew block)	Wetness (+)	2	16.3097	0	1.0000	0.4892	-5.6549
Vole (camera traps)	Wetness (+)	2	14.1247	0	1.0000	0.2978	-4.2052
	Stem Density (+)	2	15.2607	1.1360	0.5667	0.1687	-4.7732
Gopher	Wetness (-)	2	22.0976	0.0000	1.0000	0.2541	-8.5873
	Rush (-)	2	22.9178	0.8202	0.6636	0.1686	-8.9974
	Combined (Wetness (-), Rush (-))	3	23.4494	1.3518	0.5087	0.1293	-7.7247
	Null	1	23.4557	1.3582	0.5071	0.1289	-10.5850

Discussion

Great gray owls are a California endangered species and the subspecies found in Yosemite National Park, *Strix nebulosa yosemitensis*, is genetically distinct from other subspecies (Hull et al. 2010). The core distribution of this population occurs in YOSE, making great gray owls in Yosemite critical to the long-term persistence of this subspecies. Gophers and voles are the main prey species for YOSE great gray owls (Reid 1988) and prey availability is key to explaining owl occurrence across the park (van Riper et al. 2013). However, at one critical mid-elevation meadow complex within the park, the Ackerson Meadow complex, a recent study (Kalinowski et al. 2014) found evidence of gophers but only limited vole occurrences (R. Kalinowski, pers. comm.), though survey effort was not comprehensive across the meadow complex, and voles are known to experience population cycles so temporally limited sampling efforts may not adequately capture vole populations (Krebs 1966; Lidicker 1988; Pinter 1988). This meadow complex is the target of restoration efforts, in part to support the resilience and persistence of great gray owls (Ackerson Meadow Restoration Environmental Assessment 2021). Thus, in this project, we sought to inventory great gray owl prey in and around the Ackerson Meadow complex using multiple approaches across two years, in order to provide baseline data on great gray owl prey populations. Specifically, we assessed whether the presence and/or abundance of great gray owl prey (primarily gophers and voles) varied by site, habitat type and habitat properties, or through time, in YOSE.

Variation of Great Gray Owl Prey in Focal Yosemite NP Meadows

We surveyed the great gray owl prey population using multiple methods in the spring and summer of 2023 and 2024 and found evidence for the presence of both gophers (*Thomomys* spp.) as well as voles (*Microtus* spp.). Overall, we did not find strong spatial or temporal variation in great gray owl prey populations, though this was in part due to limited sampling across the survey period and in part because of many zeros in the final dataset. However, our findings echo and contribute to results from previous surveys in the region (Kalinowski et al. 2014) that showed that gophers are relatively common across sites and years, but voles are more uncommon.

Gophers were detected at all three sites (Ackerson Main, Ackerson South, and Hodgdon Meadow) and were overall relatively prevalent across sites and grids, occurring at 10 of 16 (62.5%) total sampling grids. Gophers tended to be found more often on the forest grids (they occurred at 7 of 8 (87.5%) forest grids versus 3 of 8 (37.5%) meadow grids), and while there was no difference in gopher activity between forest and meadow grids (Figure 6), anecdotally the activity that occurred in the meadow grids was only on the forest edge of the grid. Gopher presence was negatively associated with soil wetness and the presence of rushes in the final logistic regression model (Table 2), but the model overall was a poor fit for explaining gopher presence and absence and the top models including soil or habitat variables did not substantially differ from the null model. The data from this study is consistent with findings from Kalinowski et al. (2014), who also found a negative association between gopher abundance and soil wetness, as well as with evidence that gophers seasonally relocate away from meadows to avoid the spring accumulation of surface water (Ingles 1949). It is also consistent with evidence that gopher density is higher in grazed meadows with

shorter vegetation, which is likely also associated with more exposed and drier soil in grazed meadows (Powers et al. 2011).

Voles are the other main component of great gray owl diet (Reid 1988). We found *Microtus montanus* voles at four of the 16 individual live trapping grids in our study (33%). The overall maximum abundance of voles ranged from 0 to 27 voles per trapping grid, with an average of 2.25 voles and a median of zero voles per grid. On the grids with voles, there was a mean maximum abundance of 9 voles per grid. Voles were only detected at the two Ackerson sites and exclusively in meadow habitats based on live-trapping data (Figure 5), though voles were detected on cameras in two forest grids at the meadow edge of the grid. Previous research by Kalinowski et al. (2014) also found that vole prevalence was quite low across two years in the southern Sierra Nevada. Voles were found only at 37–38% of the surveyed meadows, with a mean abundance of fewer than two voles per trapping web across years. Kalinowski et al. sampled both Ackerson Main and Ackerson South, and similar to our results, found variable vole presence across sites and years. They did not detect voles in Ackerson Main in 2010 or 2011 nor in Ackerson South in 2010, though they did detect voles in Ackerson South in 2011 (R. Kalinowski, pers. comm.). The variable nature of vole presence is potentially related to vole population cycles (e.g., Krebs 1966; Lidicker 1988; Pinter 1988). In the central Sierra Nevada, *Microtus montanus* population abundances fluctuate strongly within a year and also fluctuate across years, experiencing irregular booms in population density every 3–5 years (Fitzgerald 1977). The existence of both annual and seasonal population fluctuations could account for the fact that voles were often not detected, but when they were, they tended to be quite abundant and visible (Figure 5, Figure 8).

Due to our sampling design, we had three different measures of vole presence/absence: voles detected via live-trapping, voles detected on camera traps, and voles detected through removal of chew block material. All three measures were strongly consistent with one another, reinforcing the suitability of both camera traps and chew blocks for detecting voles (Figure 9, Figure 10). Across measures, soil wetness emerged as a potential predictor of vole presence, though the final models were not strong overall (Table 2). Overall, our results are consistent with the habitat associations of *Microtus montanus* voles, which are strongly associated with grassy, meadow habitats (Sera and Early 2003). However, the relationship between vole presence and soil wetness is relatively weak and may disappear with inclusion of more relevant habitat variables. For example, Kalinowski et al. (2014) tested for associations between voles and soil wetness and did not find any, but instead found strong associations between vole presence and sward height and presence of corn lily, two habitat variables we did not include in our study.

Chew Blocks Provided a Reliable Metric of Vole Presence and Activity

Live trapping is time and labor intensive, as well as potentially stressful for animals. Thus, we sought to assess whether different sampling methods would accurately detect the presence and/or relative abundances of voles in these meadows, as a reliable alternative to live trapping. A technique used in agricultural settings, chew blocks, measures the amount of material removed from a small, non-toxic chew block and provides a reliable proxy for the relative abundance of voles (Whisson et al. 2005; Engeman et al. 2016) or for rodent abundance more generally (Larson 2024). However, it is

unknown to what extent this method can reliably detect voles in a non-agricultural setting. Here, we assessed the potential of chew blocks to reliably document the presence and relative abundance of voles in a wildland setting (Yosemite National Park).

We found that chew blocks are likely to be a reliable method for establishing the presence of voles in wildland settings. We used three different sampling methods to detect the presence of voles: traditional live trapping, chew blocks, and camera traps. Note that all camera traps were baited with chew blocks, so we did not assess the reliability of camera traps on their own. All three methods indicated vole presence in Ackerson Meadow in Yosemite National Park, and the relative abundance proxies for voles were strongly correlated across these three methods (Figure 9, Figure 10). Further, we documented that chew block removal is highly likely due to voles and not other animals, based on several lines of evidence: 1) While the camera traps detected several different species of small mammals, the cameras in meadow grids (where voles were found exclusively in our live traps) only detected voles (as well as several larger-bodied Carnivora species); 2) Voles were observed on camera at every grid where voles were detected in the live traps (except for one observation in 2023, when cameras were not deployed); 3) Voles were frequently observed on camera interacting with the chew blocks at length (Appendix); 4) The amount of chew block removed was significantly positively correlated to live vole abundance (Figure 10a) and camera vole activity (Figure 10b); and 5) The amount of chew block removed was not significantly associated with gopher activity, overall small mammal species richness observed with live trapping, or overall small mammal species observed on the cameras (Appendix). The only other taxon observed clearly interacting with the chew blocks was *Peromyscus* spp. (33 total images of this taxon, some of which show the animal on or interacting with the chew block). There was a positive correlation between the amount of chew block material removed and species richness detected via the camera traps ($\rho = 0.694$, $p = 0.026$; Appendix), possibly due to sites with only one species (*Microtus* sp.) that had significant amounts of chew block material removed or sites with more than one species (typically, the forest grids) which had a relatively little, but non-zero, amount of chew block material removed. This could indicate that other animals eat chew block material, but overall, our combined evidence indicates that the vast majority of chew block material removed was consumed by voles.

Chew blocks potentially provide managers with an easy-to-deploy tool for censusing voles. One next step is testing whether this tool varies in reliability among vole species. We only found *Microtus montanus* in the live traps. Camera images were classified to genus, but likely are also *M. montanus* based on the short tails. Other indirect measures of vole abundance, such as runways, vary by species—for example, long-tailed voles (*M. longicaudus*) are not as strongly associated with runways as montane voles (Smolen and Keller 1987). However, the voles in the agricultural settings tested (e.g., Engeman et al. 2016; Whisson et al. 2005) are *M. californicus*, and chew blocks are a reliable measure for that species as well, which is promising for the applicability of chew blocks across species. One other caveat is that the overall small mammal diversity at our survey sites was low (consistent with other trapping efforts in 2023 and 2024 elsewhere in the park; R. Warnert and J.L. Blois, unpublished data), so the proxy may break down in higher richness systems, where species other than voles may target the chew blocks. Overall, though, our results show that deploying chew

blocks, with or without associated cameras, is a reliable method for detecting voles in Yosemite National Park, echoing support for this method from other settings.

Limitations and Caveats to the Great Gray Owl Prey Inventory

Due to various real-world limitations, such as funding delays, shipping delays, and personnel illness, we were not able to sample as extensively as desired. Thus, sample size was relatively limited. Additionally, our data on animal recaptures is inconsistent, limiting estimates of population abundance. Despite this, our results are relatively consistent with other work in the area, and found stable and relatively prevalent gopher populations and more variable vole populations. When voles were found, they tended to be relatively abundant, and this was seen in all three metrics of vole abundance (live trapping, cameras, and chew blocks), lending confidence to the patterns of relative abundances among sites. The strong correlations among different proxies of vole abundance also lend support to the use of chew blocks in wildland settings.

Implications for Ackerson Meadow Restoration

The Ackerson Meadow project is an ambitious project aimed at restoring the function of a critical mid-elevation meadow that was historically degraded by cattle grazing and other activities. This restoration would bolster meadow habitat for several focal species, among them great gray owls (Ackerson Meadow Restoration Environmental Assessment 2021). Ackerson Meadow is a large meadow complex, and most of the early restoration activities (initiated in August 2023) focus on the main meadow within the complex (see Figure 1). A more southerly meadow within the complex (Ackerson South, see Figure 1) was relatively less impacted to begin with, and both Ackerson South and the nearby Hodgdon Meadow serve as relatively intact “control” meadows to which differences in great gray owl prey can be compared. While variation among meadows in most metrics of great gray owl prey presence and abundance was not significantly different, likely due to low sample sizes, there tended to be higher amounts of prey in Ackerson South than either Ackerson Main or Hodgdon Meadows. Also, no voles were detected at Hodgdon Meadow over the course of the surveys and it had the lowest amount of gopher activity detected. Overall, gophers were prevalent across sites and years, and while meadow restoration may negatively affect them due to increases in soil wetness, even with restoration there should be ample gopher habitat available at meadow edges and within the forest. Thus, the restoration has the most potential to positively impact vole populations, especially in Ackerson Main, and potentially shift vole populations closer towards abundances seen in Ackerson South (recognizing that due to limited sample size and high variance, there were no significant differences in vole populations among sites). This inventory will also provide a foundation for future efforts focused on detecting the impacts of the restoration on great gray owl prey.

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Appendix

Figures 11 through 20 show additional results for this study, while Figure 21 shows a vole chewing on a chew block at a study site. Table 3 contains details about the effort associated with the live traps, chew blocks, and camera traps that were deployed for this study.

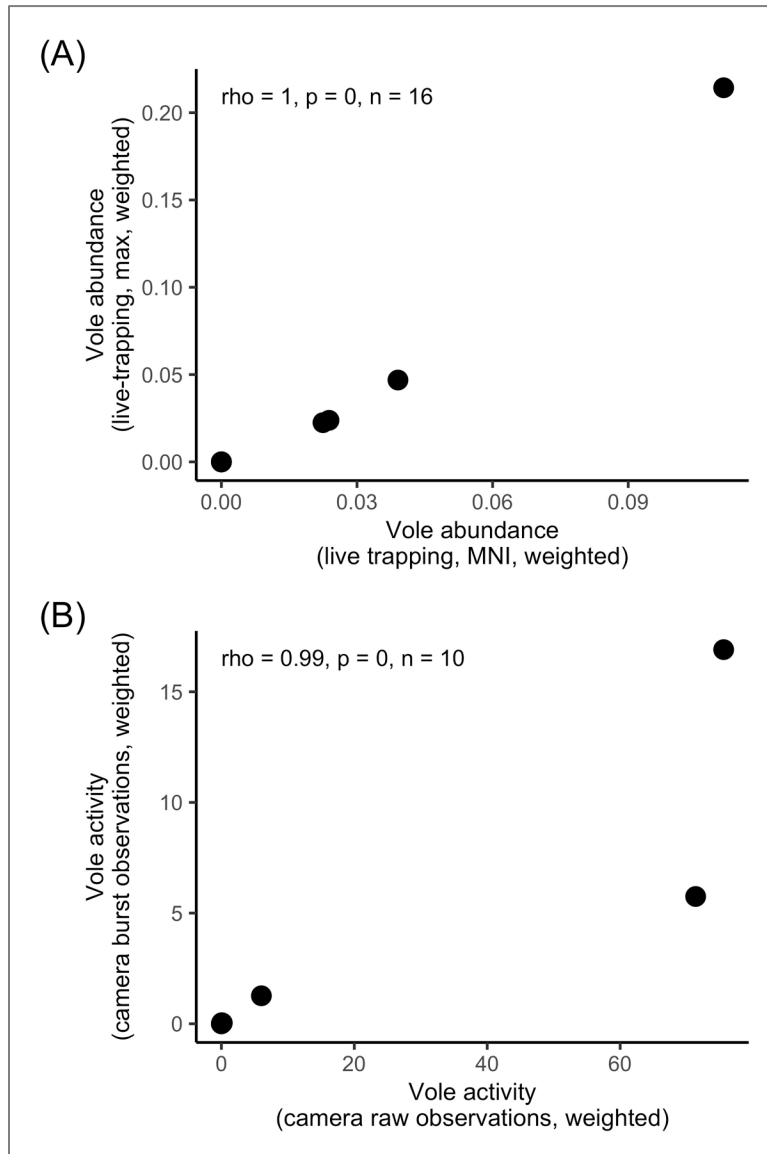


Figure 11. Correlation between different measures of vole abundance within a grid. (A) Correlation between maximum (max) vs. minimum number of individuals (MNI) estimates of vole abundance based on live trapping grids. (B) Correlation between vole activity based on the raw number of camera images of voles vs. the number of camera bursts that detected a vole. All estimates have been weighted by sampling effort.

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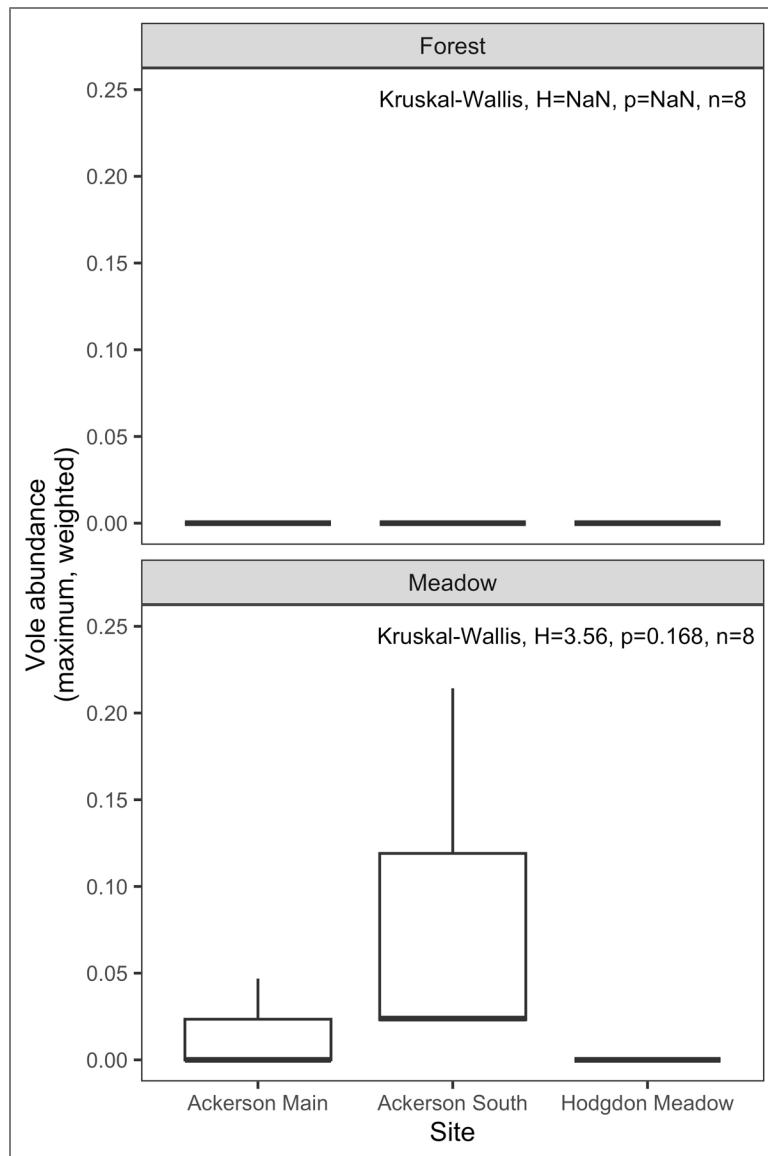


Figure 12. Vole abundance across sites and grid habitat, measured via live-trapping.
NPS / JESSICA BLOIS

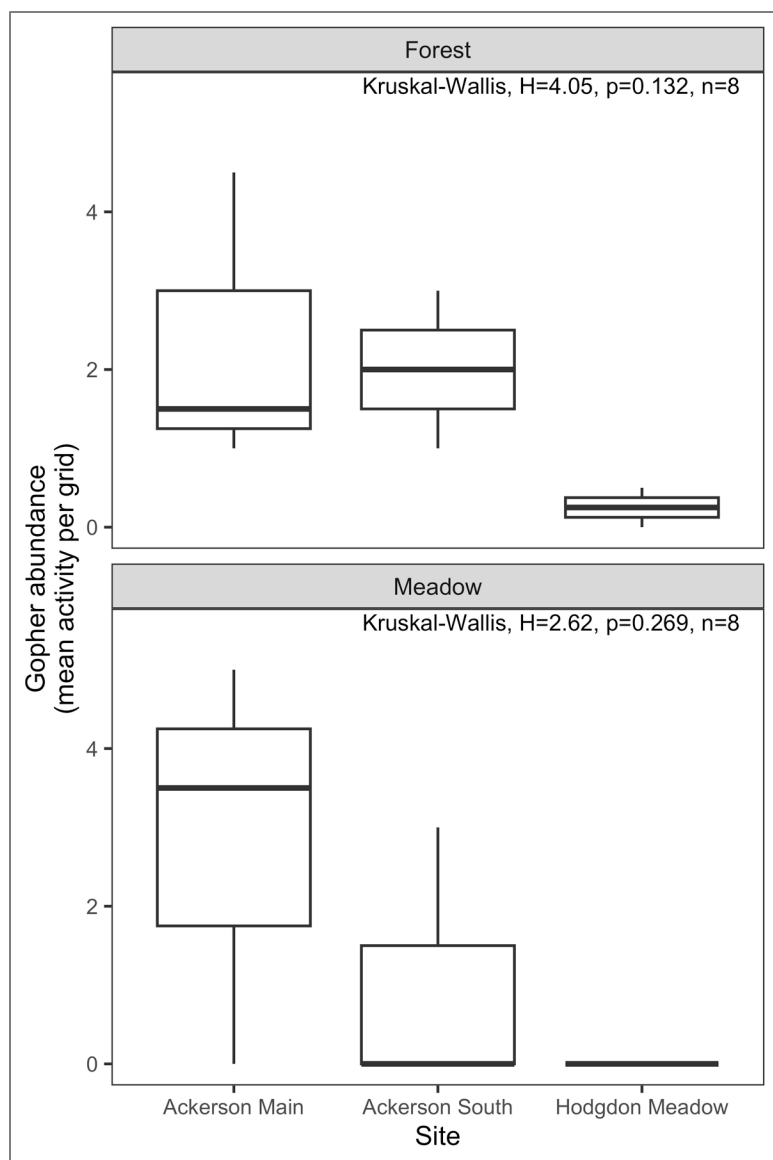


Figure 13. Gopher activity as a proxy for gopher abundance across sites and grid habitat.
NPS / JESSICA BLOIS

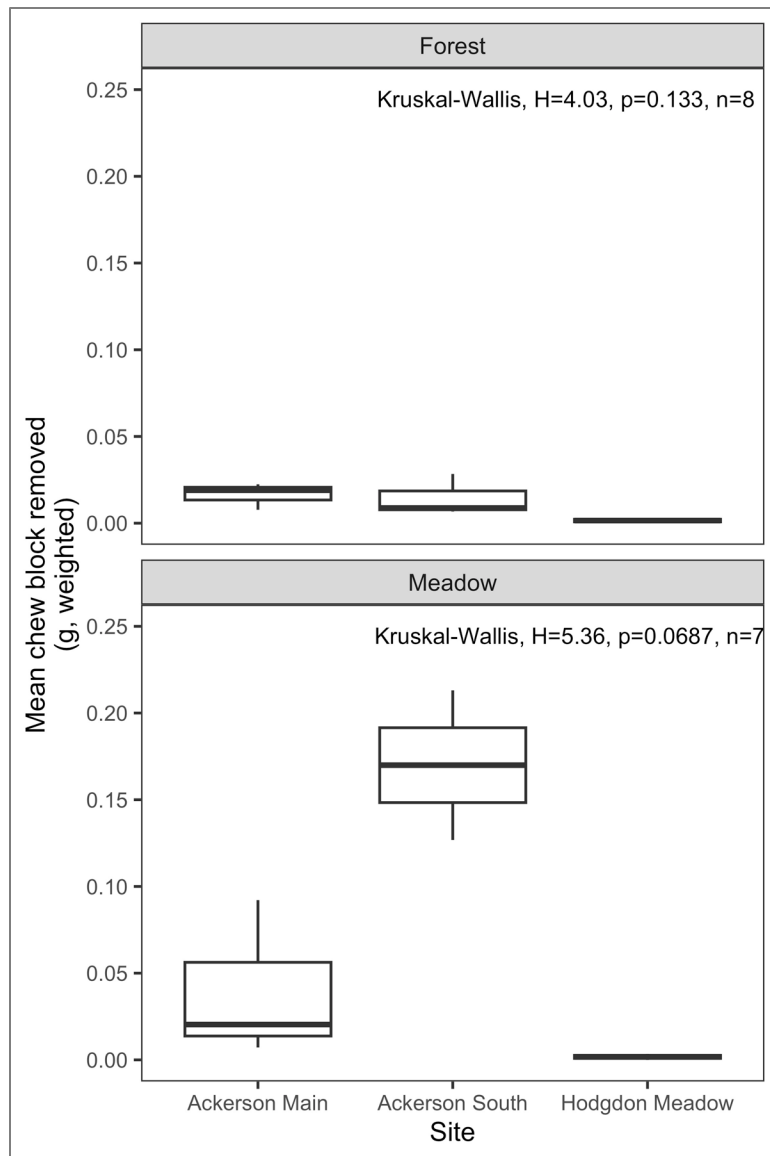


Figure 14. Chew block material removed across sites and grid habitat.
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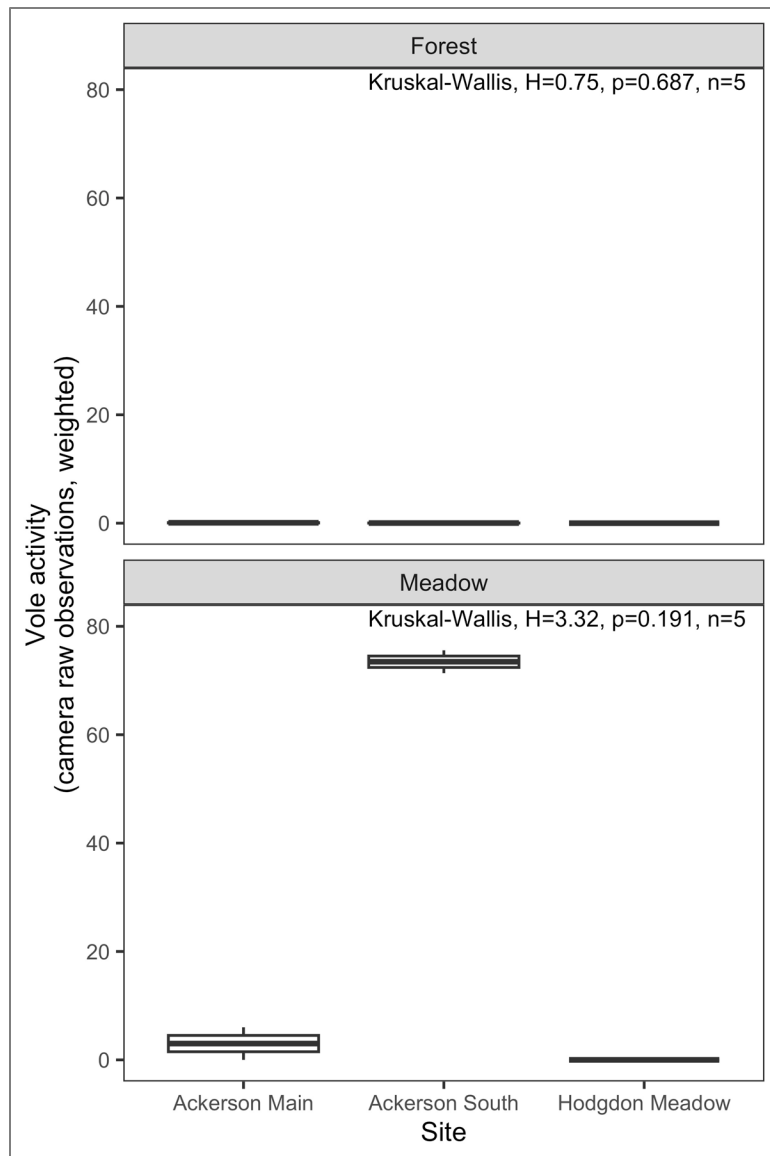


Figure 15. Vole activity observed on cameras across sites and grid habitat.
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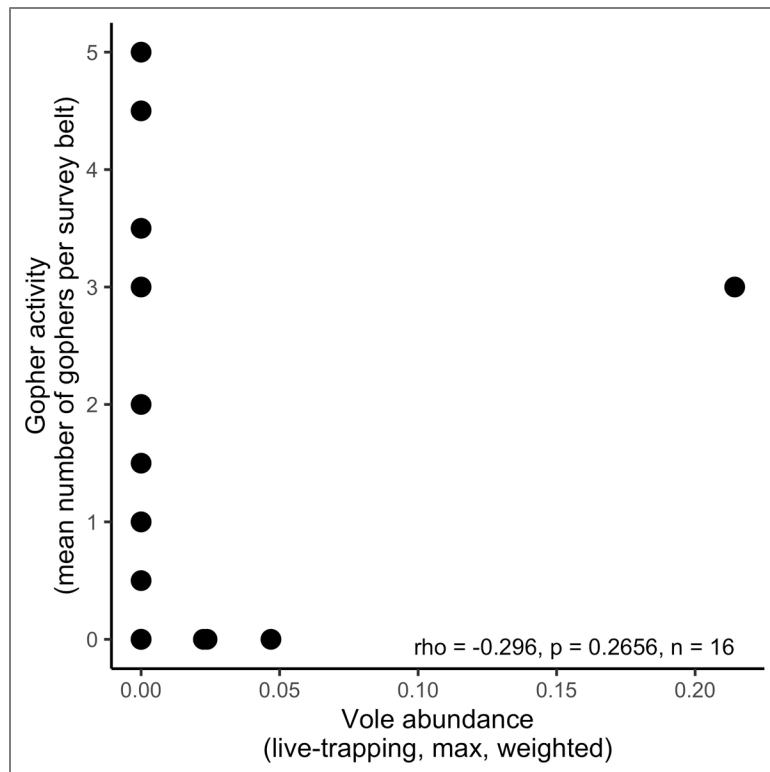


Figure 17. Correlation between vole abundances and gopher activity across sites.
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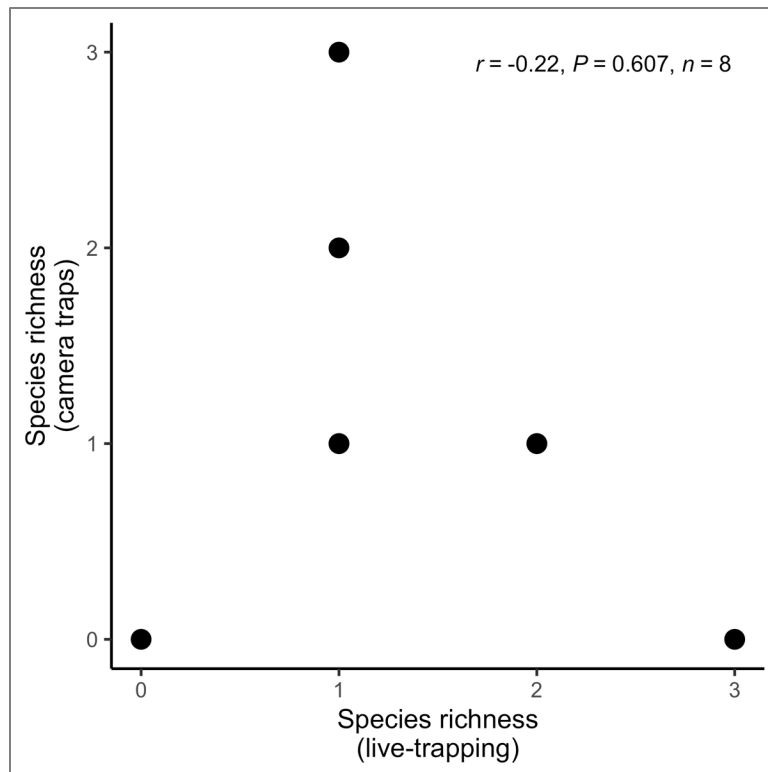


Figure 18. Correlation between two estimates of species richness at each sampling grid: species richness estimates via live trapping and species richness estimated from the camera traps.

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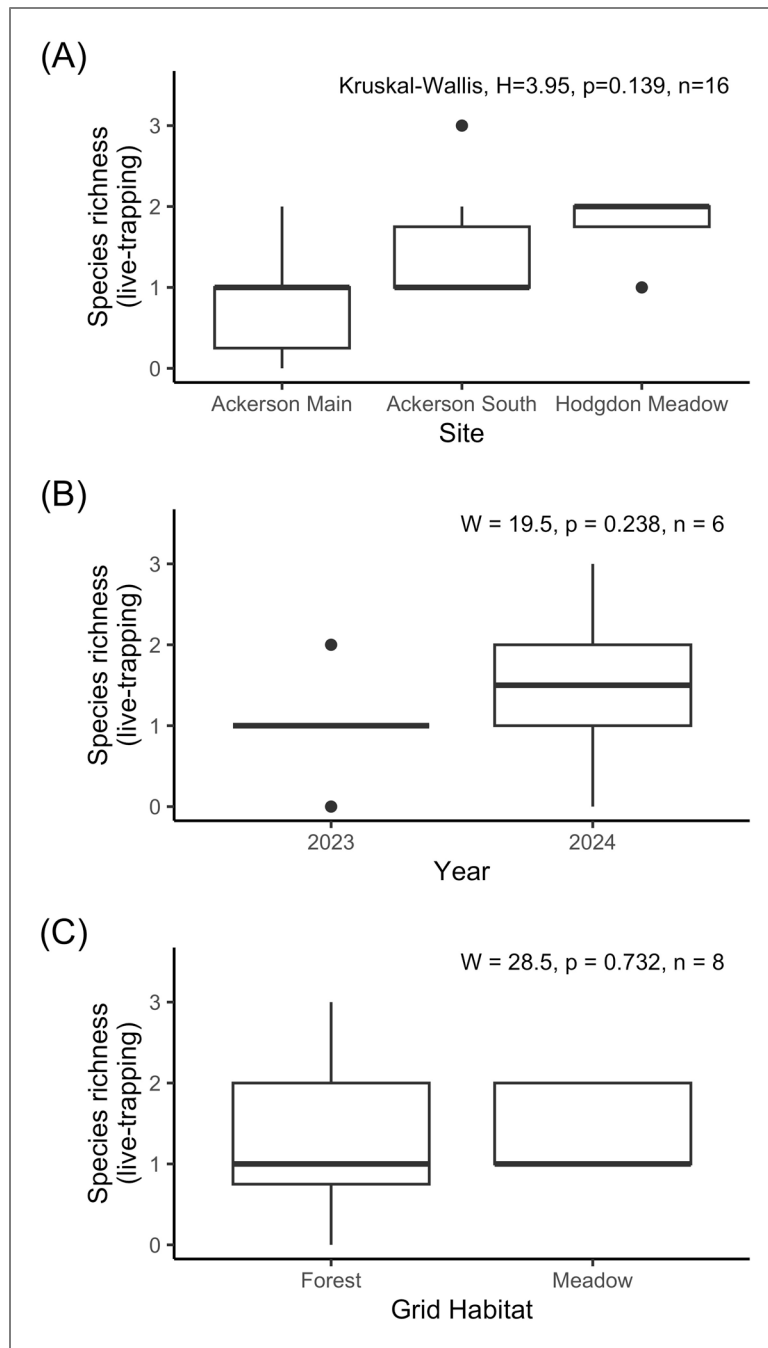


Figure 19. Species richness across (A) sites, (B) years, and (C) grid habitats, detected via live trapping. There were no significant differences in species richness among sites, years, or grid habitats.

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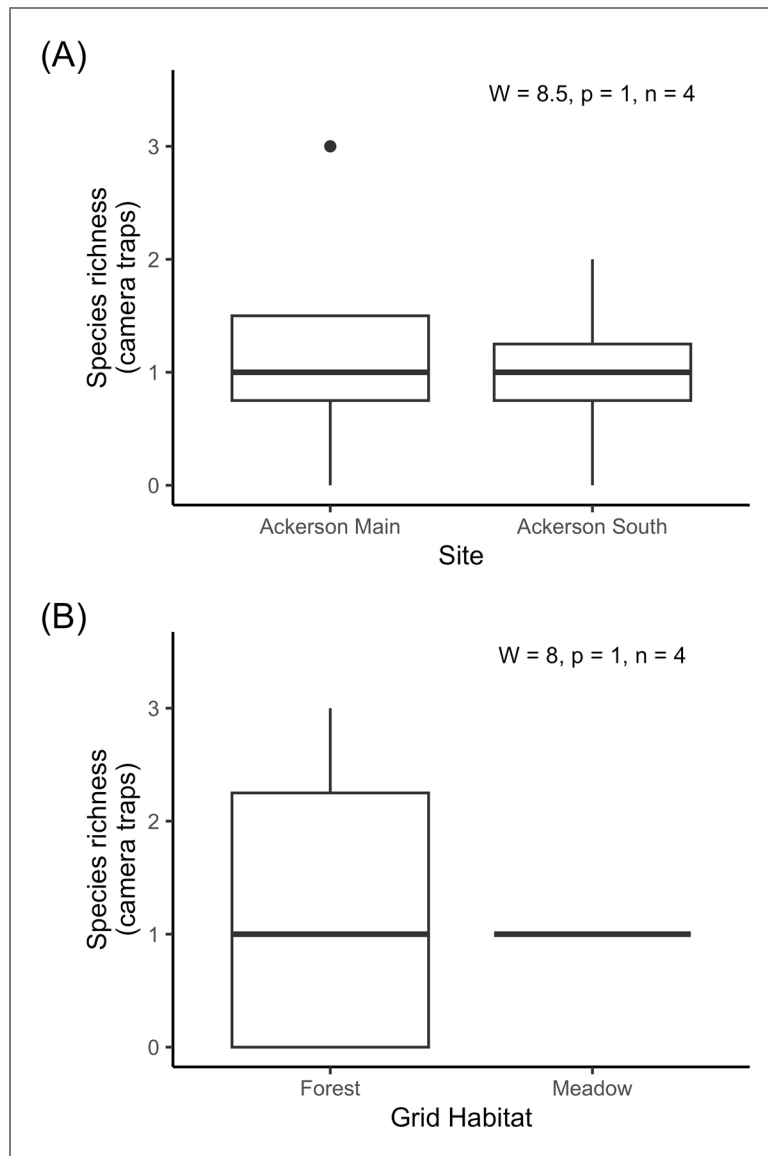


Figure 20. Species richness across (A) sites and (B) grid habitats, estimated via camera observations. There were no significant differences in species richness among sites or grid habitats.

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Figure 21. A vole (*Microtus* sp.) chewing on a chew block at Ackerson South, Meadow grid, in the early sampling period of 2024, chew block position C5.

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Table 3. Detailed effort for live traps, chew blocks, and camera traps.

Site	Grid	Year	Period	Sample	Date Deployed	Date Removed	Base Number of Trap Nights	Number of Traps	Adjustments	Total Number of Trap Nights	Live Trap Arrangement
Ackerson Main	Forest	2023	Late	Live	8/7/2023	8/11/2023	4	32	0	128	4 Tomahawk; 12 small Shermans; 16 large Shermans
	Meadow	2023	Late	Live	8/7/2023	8/11/2023	4	32	0	128	4 Tomahawk; 12 small Shermans; 16 large Shermans
	Central	2023	Late	Live	8/7/2023	8/11/2023	4	32	0	128	4 Tomahawk; 12 small Shermans; 16 large Shermans
	Forest	2023	Late	Chew	8/8/2023	8/11/2023	3	32	0	96	–
	Meadow	2023	Late	Chew	8/8/2023	8/11/2023	3	32	0	96	–
	Central	2023	Late	Chew	8/8/2023	8/11/2023	3	32	0	96	–
	Forest	2024	Early	Live	5/27/2024	5/31/2024	4	32	0	128	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Meadow	2024	Early	Live	5/27/2024	5/31/2024	4	32	0	128	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Forest	2024	Early	Chew	5/28/2024	5/31/2024	3	32	0	96	–
	Meadow	2024	Early	Chew	5/27/2024	5/31/2024	4	32	0	128	–
	Forest	2024	Early	Camera	5/28/2024	5/31/2024	3	7	21	42	–
	Meadow	2024	Early	Camera	5/27/2024	5/31/2024	4	7	25	53	–
	Forest	2024	Late	Live	7/22/2024	7/26/2024	4	32	0	128	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Meadow	2024	Late	Live	7/22/2024	7/26/2024	4	32	0	128	4 Tomahawk; 20 small Shermans; 8 large Shermans

Table 3 (continued). Detailed effort for live traps, chew blocks, and camera traps.

Site	Grid	Year	Period	Sample	Date Deployed	Date Removed	Base Number of Trap Nights	Number of Traps	Adjustments	Total Number of Trap Nights	Live Trap Arrangement
Ackerson Main (cont.)	Forest	2024	Late	Chew	7/22/2024	7/26/2024	4	32	0	128	–
	Meadow	2024	Late	Chew	7/22/2024	7/26/2024	4	32	0	128	–
	Forest	2024	Late	Camera	7/22/2024	7/26/2024	4	7	0	28	–
	Meadow	2024	Late	Camera	7/22/2024	7/26/2024	4	7	0	28	–
Ackerson South	Forest	2023	Late	Live	7/31/2023	8/4/2023	4	35	0	140	5 Tomahawk; 8 small Shermans; 22 large Shermans
	Meadow	2023	Late	Live	8/1/2025	8/4/2023	3	14	0	42	0 Tomahawk; 0 small Shermans; 14 large Shermans
	Forest	2023	Late	Chew	8/1/2023	8/4/2023	3	35	0	105	–
	Meadow	2023	Late	Chew	NaN	NaN	0	0	0	0	–
	Forest	2024	Early	Live	6/4/2024	6/7/2024	3	32	–10	86	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Meadow	2024	Early	Live	6/4/2024	6/7/2024	3	31	–4	89	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Forest	2024	Early	Chew	6/4/2024	6/7/2024	3	32	0	96	–
	Meadow	2024	Early	Chew	6/4/2024	6/7/2024	3	32	0	96	–
	Forest	2024	Early	Camera	6/4/2024	6/7/2024	3	7	0	21	–
	Meadow	2024	Early	Camera	6/4/2024	6/7/2024	3	7	0	21	–
	Forest	2024	Late	Live	7/15/2024	7/19/2024	4	32	–3	125	4 Tomahawk; 20 small Shermans; 8 large Shermans

Table 3 (continued). Detailed effort for live traps, chew blocks, and camera traps.

Site	Grid	Year	Period	Sample	Date Deployed	Date Removed	Base Number of Trap Nights	Number of Traps	Adjustments	Total Number of Trap Nights	Live Trap Arrangement
Ackerson South (cont.)	Meadow	2024	Late	Live	7/15/2024	7/19/2024	4	32	-2	126	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Forest	2024	Late	Chew	7/15/2024	7/19/2024	4	32	0	128	—
	Meadow	2024	Late	Chew	7/15/2024	7/19/2024	4	32	0	128	—
	Forest	2024	Late	Camera	7/15/2024	7/19/2024	4	7	0	28	—
	Meadow	2024	Late	Camera	7/15/2024	7/19/2024	4	7	0	28	—
Hodgdon	Forest	2023	Late	Live	8/7/2023	8/11/2023	4	32	0	128	4 Tomahawk; 12 small Shermans; 16 large Shermans
	Meadow	2023	Late	Live	8/7/2023	8/11/2023	4	29	0	116	4 Tomahawk; 12 small Shermans; 13 large Shermans
	Forest	2023	Late	Chew	8/8/2023	8/11/2023	3	32	0	96	—
	Meadow	2023	Late	Chew	8/8/2023	8/11/2023	3	31	0	93	—
	Forest	2024	Early	Live	6/3/2024	6/7/2024	4	32	0	128	4 Tomahawk; 20 small Shermans; 8 large Shermans
	Meadow	2024	Early	Live	6/3/2024	6/7/2024	4	29	0	116	3 Tomahawk; 18 small Shermans; 8 large Shermans
	Forest	2024	Early	Chew	6/4/2025	6/7/2024	3	32	0	96	—
	Meadow	2024	Early	Chew	6/4/2025	6/7/2024	3	32	0	96	—
	Forest	2024	Early	Camera	6/4/2025	6/7/2024	3	6	0	18	—
	Meadow	2024	Early	Camera	6/4/2025	6/7/2024	3	6	0	18	—

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