Bridging the gap between pest control and conservation through effective management of Columbian ground squirrels *Urocitellus columbianus* in a national park

by

Brianna M. Lorentz

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Abstract

1. Infrastructure development can displace wildlife and lead to human-wildlife conflict, which typically requires non-lethal solutions when it occurs in protected areas. The Columbian ground squirrel (*Urocitellus columbianus*) is a small burrowing mammal that is prevalent in the mountain parks near human habitation and so it is frequently a source of human-wildlife conflict and is impacted by infrastructure development. Translocation and deterrence from burrows are two potential tools to mitigate these conflicts but their efficacy is not well-studied or understood.
2. We addressed this issue in Jasper National Park where we trapped, marked, and monitored the presence of 61 marked Columbian grounds squirrels (hereafter 'squirrels'). We translocated 31 animals in four groups of sympatric individuals to a prepared release site and compared their apparent survival to that of 30 squirrels that were not translocated using Kaplan-Meier estimates. We evaluated hazards associated with translocation, age and sex classes, and year of translocation using Cox proportional hazards analysis. We tested the effect of deterrence on squirrel activity by blocking 157 burrows at two sites with wooden stakes, pool noodles, or a combination of stakes and hardware cloth and monitored them for signs of re-entry. At one site, we used logistic regression to estimate the probability of re-entry based on blocking method and whether the burrow was regularly sprayed with a scent deterrent (coyote, *Canis latrans*, urine). At both sites we also investigated the change in re-entry events over the 8-week monitoring period using a chi-square test.
3. Apparent annual survival, measured as detection at the release site, between July 2020 and May 2022 was 75% for control squirrels and 8.7% for translocated squirrels. As binary comparisons, hazards were higher for translocated squirrels in both years with no difference in hazards between sex or age classes. The likelihood of burrow re-entry was not predicted by any of block

type, the use of spray, or their interaction; similarly burrow isolation did not predict reentry likelihood. There was a greater number of re-entry events in the first half of the monitoring period at one site and a greater number in the second half at the other site.

4. We suggest that retention and apparent survival was lower for translocated squirrels because of increased rates of predation, conflict with conspecifics, or dispersal from the site. Cost-effective mitigation for this species may include robust deterrence with sturdy materials, but the ethical use of this method may require that suitable habitat is available or augmented nearby. Mitigation of conflict involving squirrels might begin with increased public awareness of the ecological roles of squirrels to support greater tolerance of squirrel activity, particularly in protected areas. When squirrels must be removed from an area quickly and lethal management is undesired, translocation is unlikely to support survival comparable to resident squirrels. Deterrence success may be enhanced by reducing local habitat attraction (e.g., mowed lawns), augmenting adjacent habitat (e.g., by providing fertilizer, cover or starter burrows), and maintained with fertility control, which has been applied to other species of ground-dwelling rodents.

Preface

This thesis is an original work by Brianna M. Lorentz. Publication of this research is intended with coauthors M. Bradley G. Lajeunesse, E. Smith, E. Holden, and C.C. St. Clair in *Ecological Solutions and Evidence* and has been formatted, where applicable, to the requirements of the journal. Appendices may be included as supplemental material. B. Lorentz led data collection, analyses, and manuscript preparation. M. Bradley proposed the project, secured most of the funding for it, assisted in project design, provided feedback throughout, and comments on the manuscript. G. Lajeunesse assisted in literature and data collection, and development of the deterrence and translocation protocols. E. Smith assisted with data collection and completed independent research on habitat selection of Columbian ground squirrels in support of this project with assistance from E. Holden. C. C. St. Clair drafted the study design, supported field work, provided feedback throughout the project, and assisted in data analysis and manuscript preparation. The research project, of which this thesis is a part, received animal ethics approval from the University of Alberta Animal Care Committee (AUP00003568) and the Parks Canada Animal Care Committee. Work occurred under Parks Canada research permit JNP-2020-35697.

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Introduction

Habitat destruction and associated displacement of species, whether abundant or rare, is often caused by infrastructure projects such as roads and buildings to support human population growth or activity (Benítez-López et al. 2010; Crooks et al. 2017; Barnick et al. 2022). Species that are not displaced by development are sometimes associated with human-wildlife conflict, which is especially likely if they become more abundant in the presence of humans or exploit human infrastructure (Messmer 2009; Nyhus 2016). Historically, these conflicts have been managed using lethal means, but those techniques are increasingly unsupported by the public (Craven et al. 1998; Drijfhout et al. 2022) and they are inappropriate for native species in protected areas (Martinez-Jauregui 2020). These changing circumstances create an increasing need for non-lethal tools to mitigate human-wildlife conflict (Massei and Cowan 2010; Germano et al, 2015).

Among many other species throughout the world, the challenge of managing a human-exploiting species without lethal means in a protected area applies to Columbian ground squirrels (*Urocitellus columbianus*) in the mountain national parks of Alberta and British Columbia. The Columbian ground squirrel is a semi-fossorial, social species occupying mountainous regions of North America (King and Murie 1985; Hare and Murie 1996). Like other burrowing mammals, squirrel presence and burrowing activities provide important ecosystem functions by aerating and mixing soil, stimulating plant growth, dispersing seeds, recycling nutrients, and providing a prey source for other species (Delibes-Mateo 2011; Davidson et al. 2012). However, these animals are also adept at exploiting spaces adjacent to human occupation, especially grazed and mowed areas, such as pastures, meadows, and lawns, and, like other ground squirrels, use the presence of people as protection from predators (Swaisgood et al. 2019).

In Jasper National Park, Columbian ground squirrels are prevalent in and near the town site, including areas that are being developed for new roads, campsites, and buildings. The governing agency, Parks Canada, has a mandate to protect ecological integrity (Parks Canada 2019) and balance the needs of both humans and wildlife (O'Brien et al. 2016; Choi et al. 2017). Consequently, its recent policy requires that building proponents capture and move squirrels to suitable habitat nearby, but no work has documented the fate of those animals and there is no specific protocol for conducting translocations. Similarly, some recreational facilities and accommodations in the park have blocked burrows to deter squirrels from areas of conflict, but again without standardizing the materials and methods used, or measuring the efficacy of these approaches. A growing literature provides information on both techniques as non-lethal solutions for human-wildlife conflict. These resources include information on burrow destruction and exclusion (Gilson and Salmon 1990), translocation (Van Vuren et al. 1997, Gedeon et al. 2011, Koshev et al. 2019) and multiple methods that include exclusion, burrow destruction, and translocation (Proulx and Mackenzie 2009).

Translocation, which is defined as the deliberate movement of wildlife from one location to another by humans (Batson et al. 2015), has long been used to augment declining or extirpated populations of species at risk (Fischer and Lindenmayer 2000) including ground-dwelling rodents such as black-tailed prairie dogs (*Cynomys ludovicianus;* Shier 2006), kangaroo rats (*Dipodomys* spp.; Tennant et al. 2013), and Vancouver Island marmots (*Marmota vancouverensis*; Lloyd et al. 2019). More recently, translocation has been used to mitigate human-wildlife conflict with more abundant species such as woodchucks *(Marmota monax;* Lehrer et al. 2016), hairy-nosed wombats (*Lasiorhinus latifrons*; O'Brien et al. 2021*),* and red diamond rattlesnakes *(Crotalus ruber;* Corbit and Hayes 2022*).* There is also new potential to combine these paradigms of conservation biology and pest management by using translocations to move species that are prone to conflict in some locations to places where ecosystems might be restored by their presence and activities (Swaisgood et al. 2019). Several studies identified circumstances that increase the success of translocations for ground-dwelling rodents, which include use of soft release via temporary containment areas (Wiggett and Boag 1986a; Bright and Morris 1994), provision of shelter and supplemental food (Germano et al. 2013; Davidson et al. 2018; Tetzlaff et al. 2019), and preparation of release habitat to reduce vegetation height and density (Hennessy et al. 2016; Swaisgood et al. 2019). Nonetheless, the success of translocations appears to be highly variable among both species and individuals (Villasenor et al. 2013; Lehrer et al. 2016; Bauder et al. 2020; Kachamakova et al. 2020; O'Brien et al. 2021). Although translocations have been conducted with Columbian ground squirrels to support basic research (Wigget and Boag 1986; Lane et al. 2019), there has been no study of translocations to support their conservation or management.

Deterrence is a second non-lethal tool for managing conflict with rodents and consists of auditory, visual, chemical, or physical features that are intended to discourage or prevent use of occupied areas (Conover 2021; DeLiberto et al. 2018). Exclusion based deterrence using physical barriers has been used extensively for European badgers (*Meles meles*; Ward et al. 2016). Chemical deterrents have been tested for birds such as ring-necked pheasants (*Phasianus colchicus*) and common grackles (*Quiscalus quiscula;* Werner et al. 2010) as well as rodents such as Richardson's ground squirrels (*Urocitellus richardsonii*) and house mice (*Mus musculus*; DeLiberto et al. 2018).

The purpose of this project was to determine the efficacy of both translocation and deterrence for managing Columbian ground squirrels in Jasper National Park with the potential to generalize to other mountain parks and ground-dwelling squirrels. Our specific objectives were to (1) determine apparent survival rates of translocated squirrels and compare them to squirrels that were not translocated; (2) measure site fidelity of translocated ground squirrels; and (3) suggest protocols for translocating and deterring ground squirrels to mitigate conflict. We achieved these objectives using study sites in and near the town site of Jasper, Alberta, where squirrel mitigation was required for recent or planned infrastructure projects.

Materials and Methods

Study Areas

Our study sites included three areas in or near the townsite of Jasper in Jasper National Park and one site approximately 10 km north of the townsite (Figure 1). In preparation for our study, one author (MB) surveyed the broader area for squirrel burrows and marked their locations with a GPS (Appendix A, Figure 1). Site 1 was a 1.5 ha area located immediately north of the Forest Park Hotel where a new police detachment is to be built. This site included three zones; a recently fenced area within which squirrels were captured for translocation (Zone A), a set of burrows where we conducted deterrence experiments (Zone B), and the burrows of 31 squirrels that served as controls for measuring the survival of translocated squirrels (Zone C; Figure 2). This site was formerly sparsely treed but was deforested in 2017-2018 as part of the fire prevention program and was later cleared more extensively to permit construction (Figure 3).

Coarse woody debris was burnt on site to reduce fuel load. The western edge of the site had moderate shrub cover, several tree stumps, and a few scattered squirrel burrows. This area was bordered by a recreational trail running north-south and contained an old road, also running north-south. Further east was an area with a broader mix of vegetation that contained most of the squirrel burrows. The most easterly area adjacent to the main road through Jasper (Connaught Drive) appeared to contain mostly grasses and shrubs with very few squirrel burrows. The northern section of this site, which was sparsely treed and contained a moderate number of squirrel burrows was used as a control area in which resident squirrels were not manipulated beyond capture and marking.

Site 2 was a 1.5 ha area approximately 1.5 km north of Site 1 in an open meadow that began ~200 m north of the Jasper municipal cemetery (Figure 1) where we moved all of the translocated ground squirrels. We chose this site in consultation with Parks staff after considering several other potential release sites (Appendix A). The release site was a large, apparently homogeneous, native grassland with moderate productivity typical of mesic grasslands (Figure 4). Along the western edge of the grassland, there were some shrubs and rocks, including ballast rock from an adjacent railway. A few active squirrel burrows were present near the railway and in the vicinity of the forest on the north side of the meadow and there were some inactive burrows in the southern part of the meadow where we clustered our translocations. Based on the home range sizes and dispersal distances of this and similar species (Wiggett and Boag 1986b; Villaseñor et al. 2013), we expected this site to be far enough from the release site to discourage homing. These conditions also met the recommendations of two experienced squirrel biologists, Jan Murie (professor emeritus, University of Alberta) and James Hare (professor emeritus, University of Manitoba), who suggested we choose a site with ample food that was near, but not immediately within, an existing squirrel colony. Resident squirrels on the periphery of this site were also used as controls to measure survival and were not manipulated beyond capture and marking (described below).

Site 3 was a 0.20 ha area east of Connaught Drive between Willow and Hazel Avenues (Figure 1) where a municipal waterline was installed in September 2021 and for which squirrels needed to be removed in advance. The Municipality of Jasper contracted Colliers Project Leaders to install the line and Colliers invited us to census and remove squirrels from this area.

Site 4, located at the Palisades Education Centre (Figure 1) about 10 km from the Jasper townsite. Long term staff there said that ground squirrels have always occupied a nearby grassland area but have increased their activity closer to buildings and in open green spaces used by people during the 2020 lockdown caused by COVID-19. In parts of this area, burrows create hazards for people and so facility managers conducted a deterrence experiment with our support that we include in this report.

Trapping and Census

We initiated fieldwork on 16 June 2020, following a delay imposed by the COVID-19 pandemic and associated travel restrictions. That field season continued until 14 August 2020. In 2021, field work occurred between 7 April and 28 August. In 2022, fieldwork occurred between 2 May and 26 May. All research staff were trained according to protocols created with help from Parks staff to ensure safe handling of squirrels. All animal handling protocols were also approved by both the University of Alberta Animal Care Committee (AUP00003568) and the Parks Canada

Animal Care Committee. Work occurred under Parks Canada research permit JNP- 2020-35697.

To capture ground squirrels, we placed traps baited with a small amount of peanut butter at the entrance of burrows or along squirrel paths between burrows. Once trapped, we transferred ground squirrels to cotton pillowcases or trapping bags to be weighed using a spring scale. We assessed each individual for sex, age, and breeding status. We fitted each squirrel with an aluminum ear tag on each ear, inserted a 9- digit passive integrated transponder (PIT) sub-dermally between the shoulder blades with a sterile 10- gauge needle, and applied a unique dye mark on the back using non-toxic, semi-permanent hair dye. Most juveniles received PIT tags, but not ear tags upon their first captures to prevent folding of the pinnae. We distinguished adult squirrels as those over 500 g (females) or 600 g (males) and yearlings as less than that mass; however, individuals caught near the end of the season could not accurately be distinguished between adult and yearling (Boag and Murie 1981). Juveniles were young of the year that emerged from natal burrows in June and July.

Translocation

To create a protocol for translocating Columbian ground squirrels (Appendix B), we conducted literature searches using Web of Science and Google Scholar for reintroductions and translocations of other ground-dwelling rodents. Based on recommendations by others, we prepared the release site in advance of translocations by fertilizing the vegetation using a slow release fertilizer to increase available food, mowing the vegetation below 15 cm in height to increase visibility and stimulate growth (Shier 2006; Hennessey et al. 2016; Koshev et al. 2019; Swaisgood et al. 2019), dethatching cut and dead vegetation, and digging artificial burrows of approximately 10 x 30 cm at an appropriate density or one burrow every 10 m^2 to support further burrowing activity and predator evasion (Hennessey et al. 2016). As additional cover from predators and weather, we used recent forest clearing to create piles of branches at each planned release location as suggested by another experienced researcher (Debra Shier, San Diego Zoo, personal communication). We also placed an approximately 1 m length of plastic weeping tile in the middle of the pile to simulate the cover afforded by a burrow. We monitored the piles for evidence of squirrel activity.

We targeted for translocation animals in groups of known individuals (Shier 2006) within the proposed construction footprint using a combination of trapping, logged visits to PIT tag readers situated throughout Zone A of Site 1, and visual observations. We collared adult ground squirrels intended for translocation at least one week in advance of translocation dates to minimize simultaneous stressors and to support post-release monitoring.

We moved animals either in May (2021) before young were born (Gedeon et al. 2011) or in July (2020 and 2021) after juveniles had emerged to increase survival of dependent young. At the release site, we provided translocated animals with acclimation cages consisting of a wooden frame covered in ¼ in or ½ in hardware cloth with a waterproof, hinged roof, and plastic-coated wire mesh floor, which ranged in size from 5 - 6 m^2. We cut two holes into the flooring material to align with two pre-dug burrows positioned for this purpose. We positioned enclosures approximately 1 m apart within groups of squirrels with approximately 40 m between groups of past or planned translocations.

Cages remained closed for 2-3 days following translocation during which time squirrels were provided with approximately 150 ml of food / squirrel each morning and afternoon. This volume was based on energetic requirements of this species given by Ritchie (1990). The supplemental diet consisted of organic peanut butter mixed with commercial rabbit pellets and shredded sweet potato or leafy greens (Debra Shier, San Diego Zoo, personal communication). We opened cages to release squirrels by lifting a portion of their walls and continued to provision food in or near open enclosures at a rate of approximately 150 ml / squirrel once daily. Beginning on the day of each translocation, we monitored and recorded the location of translocated squirrels daily using a combination of trapping, PIT tag readers, and, for adults, VHF telemetry. We conducted this monitoring and continued to provide food daily until 14 August 2020 and 21 August 2021 when most (2020) or all (2021) squirrels appeared to have hibernated.

At Site 1 (2020, 2021, and 2022) and Site 2 (2021 and 2022), we monitored the presence of resident squirrels to provide comparative values for the retention and survival of translocated squirrels. We did so by trapping squirrels at least once a month through their active season with a particularly focused effort at the end of each season and by using PIT tag readers placed throughout the sites in areas of known use that continuously logged squirrel visits.

Deterrence

In Zone B of Site 1, we tested methods for deterring squirrels by manipulating burrows rather than removing and translocating the animals. Within an area of approximately 30 x 70 m, we blocked 116 burrows between 6 May and 23 June 2021 (Figure 5). We blocked half of the burrows with foam pool noodles and half with wooden construction stakes and treated half of each of these groups with scent deterrent (Tink's® brand commercial coyote urine) every other day or following a precipitation event. We monitored these burrows daily for approximately seven weeks and recorded whether or not, and how, the blocking implement had been altered and if squirrels had re-entered burrows either by digging new holes or by displacing the blocking implements.

At Site 4, we tested a refined deterrence method in collaboration with property managers, Dee Jessome, Paul Langevin, and Marian McGraw, who filled burrow holes using wooden stakes and then covered them with fine gauge hardware mesh. Managers also identified an area where squirrels had occurred in recent years and augmented it for squirrels similar to our preparation at Site 2 by mowing the site, providing overhead cover (slash piles, paving stones, etc.) and digging starter burrows (Figure 6). The managers monitored 63 blocked burrows near daily for signs of re-entry from 13 July to 31 August 2021.

Statistical Analyses

We used survival analysis to examine differences in apparent survival between translocated and control squirrels. We calculated Kaplan-Meier survival estimates for 31 translocated and 30 control squirrels over a period of up to 400 days for each cohort between 17 June 2020 and 25 May 2022. We used Cox proportional hazard models to compare hazards among treatment groups and the interaction between treatment type and cohort for all squirrels and among age classes, and sex classes for translocated squirrels. We did not include as controls for survival estimates any marked squirrel that was captured only once within a translocation period, lived in the area where burrows were blocked, or did not receive a PIT tag.

We used logistic regression to investigate the effect of the type of block (stake or pool noodle) and whether the burrow was sprayed (yes or no) on the probability of re-entry, defined as a successful breach of the blocked burrow. We compared models of the variables using Akaike Information

Criterion (AIC; Burnham and Anderson 2002). To determine whether squirrels were consistently persistent over time, we used a chi-square test of independence comparing the first half of the monitoring period (weeks 1-4) with the latter half (weeks 5-8) at each of Sites 1 and 4.

Results

We trapped and marked 120 Columbian ground squirrels with 49 first-time captures in 2020, 60 in 2021, and 11 in 2022 (Appendix C). In 2020, we captured 27 females and 22 males in Zone A of Site 1 (Figure 1). In 2021, we expanded our trapping to include squirrels in the Zones B and C of Site 1. We captured and marked 27 ground squirrels at Site 1, which included 15 females and 12 males (11 adults; 16 sub-adults or juveniles). We captured and marked 25 ground squirrels at Site 2, which included 10 females and 15 males (8 adults; 17 sub-adults or juveniles including young born to the May translocation group). We trapped 6 ground squirrels at Site 3, which included 3 females and 3 males (2 adult; 4 sub-adult or juvenile). In 2022, we captured and marked 4 squirrels at Site 1 which included 2 males and 2 females (3 adults; 1 sub-adult) and 7 squirrels at Site 2 (4 males and 3 females; 4 adults and 3 sub-adults). We fitted 23 adult ground squirrels with Lotek *Ultimate Lite* very high frequency (VHF) collars.

Translocation

Of the fifteen ground squirrels we translocated in July 2020 (Cohort 1), 11 (73%) remained at the release site until presumed immergence at the end of the season approximately 20 days post-release (Figure 7). Upon emergence of the ground squirrels in the spring of 2021, we detected five of the 11 squirrels (45% of immerging squirrels, 33% of translocated squirrels; Figure 7). By the end of the 2021 season, approximately 365 days post-release, none of the ground squirrels translocated in 2020 were detected at the release site (0%). Of the sixteen ground squirrels translocated in 2021 (Cohort 2), seven (44%) remained at the release site until presumed immergence at the end of the season (Figure 7). Upon emergence of the ground squirrels in the spring of 2022, we detected five of the seven squirrels (71% of immerging squirrels, 31% of translocated squirrels).

When compared with 30 control squirrels over the period from July 2020 to May 2022, which is approximately 400 days for each cohort, the 31 translocated squirrels had 66.5% lower apparent annual survival (Table 4, Figure 8). Similarly, when cohorts were analyzed separately, translocated squirrels from cohort one had 83.3% lower apparent annual survival than control squirrels for that year and translocated squirrels in cohort two had 51.4% lower apparent annual survival than control squirrels for the subsequent year (Table 4). Separate log-rank tests demonstrated a significant difference in survival between translocation and control overall squirrels ($\chi^2 = 22.4$, $p < 0.001$; Figure 8), but also separately when measured for only cohort one ($\chi^2 = 22.6$, $p < 0.001$), and then cohort two ($\chi^2 = 5.30$, $p = 0.02$; Figure 9). A univariate Cox regression indicated that translocation produced a hazard ratio of 5.83 ($p < 0.001$), making translocated squirrels almost six times more likely to disappear than control squirrels over the approximately 400 days each cohort was monitored. There was no significant interaction between cohort and treatment (HR: -1.13, $p = 0.177$). Within the translocation group, there was a slightly higher risk associated with the juvenile age class (HR: 0.503, $p = 0.199$) and with the male sex class (HR: 0.146, $p = 0.71$).

Squirrels translocated in 2020 and 2021 remained at the release site for an average of 113.45

±140.36 days with a range of 0-380 days post-release. Squirrels translocated in 2020 remained at the release site for an average of 111.47±143.56 days, ranging from 2-327. Squirrels translocated in 2021 had a similar average number of days (115.31±141.97 days), range (0-380 days).

Deterrence

Among 94 blocked burrows at Site 1, 43 (46%) were entered by squirrels one or more times. Among 92 re-entry events (including repeated events) at these 43 burrows, 55 events (60%) occurred at 22 burrows that were blocked with pool noodles and 37 (40%) occurred at 21 burrows blocked with stakes. A similar number of re-entries occurred at burrows that had been sprayed with coyote urine (53/92) and those that were not (39/92). Successful re-entry events per burrow ranged from one to five. Although four models were within 2 AIC of the top, null model, for explaining the probability of re-entry of a blocked burrow (Table 5), the confidence intervals for each of block type, spray, and their interaction overlapped zero, indicating weak effects on burrow re-entry. Burrow isolation did not enter any retained model. At Site 1, there were more re-entry events in weeks 5-8 (33/92) than in weeks 1-4 (59/92; $x^2 = 7.35$, df = 1, $p = 0.007$).

Among the 63 burrows blocked at Site 4, 34 showed signs of attempted re-entry (54%), and 20 appeared to be successfully re-entered (32%). Opposite to what we observed at Site 1, the number of re-entry events was greater in the first half of the monitoring period (weeks 1-4; 18/20) than the latter (2/20; $x^2 = 12.8$, df = 1, $p = 0.0003$). In at least one case a squirrel dug from inside a burrow (that was connected to a burrow that was not blocked) to displace the wire mesh. Re-entry attempts continued until the end of the 2021 season and occurred again in the spring of 2022. In the 2022 season, site managers repeatedly observed ground squirrels in the areas that received habitat augmentation in 2021.

Discussion

Ground-dwelling rodents are frequent subjects of human-wildlife conflict, but they also serve important ecosystem functions (Swaisgood et al., 2019). Translocation and deterrence are non-lethal tools that could minimize conflict while maximizing ecological benefits, supporting recreational viewing, and avoiding ethical conundrums, particularly in protected areas. Use of both methods for managing squirrels is impeded by lacking information about methods and efficacy (Germano et al. 2015; Hennessy et al. 2022). We studied Columbian ground squirrels in Jasper National Park with a goal of adding to this information and assessing and guiding local use of these forms of mitigation. We found that the interannual survival of translocated squirrels was only 8.7%, compared to 75% for control squirrels (both measured over 365 days). Within those groups, juveniles had 65% lower likelihood of survival than adults and yearlings, and males had 15.7% lower likelihood of survival than females; but neither of these differences was large enough to be detected statistically ($p > 0.05$). Although about half of the burrows we blocked showed re-entry efforts or success, there was no effect on this proportion of blocking method, scent deterrence, or burrow isolation. Moreover, the relative timing of re-entry (early vs. late) differed between the two sites we monitored, all suggesting that it is difficult to predict which burrows will attract re-entry effort.

Translocated squirrels were nearly six times more likely to disappear or die than control squirrels over the two-year period of our monitoring, despite our use of recommended practices to translocate animals in groups of known individuals (Shier 2006), soft-release in cages with food, shelter, and burrows (Germano et al. 2013; Hansler et al. 2017; Davidson et al. 2018), and a release site provisioned with habitat enhancements for both food and protection from predators. Other studies of translocations in ground-dwelling rodents exhibited survival that ranged from <20% to >80% (Table 1), suggesting that translocated animals typically survive less well than animals that were not translocated, but sometimes exhibit much higher survival than we found. When translocated without habitat alteration, California ground squirrels (*Otospermophilus beecheyi*), had less than 20% survival, suggesting that mowing and digging artificial burrows is important to the survival of translocated ground squirrels (Swaisgood et al. 2019). Even with these supports, however, we found much lower survival. The higher rates of survival found in other studies may be attributed to a number of things, including the difference in the length of time animals were monitored post-release. We monitored translocated animals for at least 365 days post-release and had higher survival rates (~30%) within 100 days that later declined to >10% by 400 days.

The lengths of time translocated animals are monitored is not consistent among studies and could influence survival estimates and comparisons thereof. Lower survival of translocated animals has also been attributed to lesser food quality or quantity, greater predation, or greater dispersal from the release site (Matykiewicz et al. 2021). Others have shown that translocated animals have lower detection and survival rates post-release than control animals with some showing a 5% difference (O'Brien et al. 2021) and others showing up to a 22% difference (Villasenor et al. 2013) or even >50% difference (Swaisgood et al. 2019). Among the 31 squirrels we translocated, many were found 50 m or more from their release site on their last detection, suggesting that they were trying to leave the immediate release area. Many studies have concluded that translocated animals attempt to leave release sites (e.g., Lehrer et al. 2016; Koshev et al. 2019; O'Brien et al.

2021; Matykiewicz et al. 2021). In woodchucks (*Mormota* monax) 94% of translocated adults left the boundaries of the release site within 10 days (Lehrer et al. 2016). Similarly, for European ground squirrels (*Spermophilus citellus*), translocated individuals settled 100-720 m from the release site (Koshev et al. 2019). Movement from release sites was also noted in hairy-nosed wombats (*Lasiorhinus latifrons*), which exhibited high site fidelity, but translocated individuals ranged further than controls before settling (O'Brien et al. 2021). Lastly, translocated muskrats (*Ondatra zibethicus*) did not exhibit homing but did move an average of 2.2 km from release sites after release (Matykiewicz et al. 2021). Collars from two adult squirrels were found in a coyote den approximately 1 km east of the center of our release site, suggestive of coyote predation, and one more was found on a railway track, suggestive of removal by an unknown predator. We did not know the cause of disappearance for most of the translocated squirrels (Appendix C).

Among all squirrels that were captured at least twice, juveniles had lower survival than adults, which is consistent with previous survival estimates for this species (Boag and Murie 1981). Translocated juveniles in Cohort 1 remained at the release site longer than adults (100% of juveniles remained until the end of season 1; Figure 7), suggesting they were more tolerant than adults of translocation even if they had lower eventual survival. A similar result occurred in translocated fishers (*Pekania pennanti;* Lewis et al. 2022) in which juveniles in several cohorts had greater survival than adults. Perhaps owing to small samples sizes, we did not detect differences in the survival of males and females, although others have reported higher survival for females (Boag and Murie 1981).

Our burrow blocking experiment at Site 1 revealed no difference in re-entry rates to burrows blocked with wooden stakes relative to pool noodles, although about 50% more events (including repeated re-entries) occurred at burrows blocked with noodles. We explored pool noodles as a blocking device because we imagined they would readily conform to the curves of burrows, allowing them to be inserted to greater depths more quickly, but it appears that they did not offer enough rigidity to deter squirrels from re-entering the burrows. The wooden stakes, which were suggested by another researcher (E. S. Leyland, personal communication), may have exhibited fewer re-entry efforts because they offered more rigidity and required squirrels to dig new holes adjacent to them. Future research should investigate other methods for blocking burrows. One-way gates covering burrow holes, like those used for badgers (*Meles meles;* Ward et al. 2016) may be a better way to deter ground squirrels from an area. This technique may be especially effective when paired with a) fine-gauge metal fencing material (e.g. hardware mesh) to prevent digging adjacent to blocked burrows, b) removal of palatable vegetation around the burrow complex to reduce attraction (Ward et al. 2016), or addition of material that prevents squirrels from seeing approaching predators, and c) augmentation of an adjacent area where the squirrels can disperse once removed from the burrows of interest.

We were surprised that the application of coyote urine had no effect on burrow re-entry by squirrels because others have found that predator scents can alter the behaviour of prey species that included snowshoe hare (*Lepus americanus*) and porcupine (*Erethizon dorsatum*; Osburn and Cramer 2013), and Mojave Desert tortoises (*Gopherus agassizii*; Nafus et al. 2017). Scent deterrence may not be effective for all species though. Many do not change their behaviours in response to predator urine such as Eastern cottontail (*Sylvilagus floridanus*) and Virginia opossum (*Didelphis virginia*; Pustilnik et al. 2020); therefore, other chemical treatments may be more effective in those contexts. As one example, material treated with the purgative anthraquinone reduced the defeat of structural barriers by 50-55% in Richardson's ground squirrels (*Urocitellus richardsonii*; DeLiberto et al. 2018). Non-chemical habitat adjustments may be more effective at deterring squirrels, such as planting shrubs or installing short fences to reduce sight lines.

The seasonal behavioural changes of this species appear to affect the performance of deterrence efforts. At Site 1 where burrows were blocked after mating but before females gave birth there were more re-entry events in the latter half of the monitoring period that coincided with the emergence of young from natal chambers. Conversely, at Site 4 where burrows were blocked after the young emerged but before hibernation there were more re-entry events in the first half of the monitoring period. The phenology of the squirrels may be influencing this pattern and should therefore be considered when developing deterrence plans. Aiming to block burrows after the young emerge and before squirrels hibernate might encourage dispersal from areas of conflict into areas that are augmented.

Even with persistent effort to remove squirrels from areas near human occupation, there is a greater challenge when populations are able to grow rapidly due to the predator refugia offered by humans and their structures. Fertility control is a tool that has grown in popularity in the non-lethal management sphere and may increase the efficacy of the other methods described above. There are many forms of fertility control including implants, injections, and oral administration of hormones (Massei and Cowan 2014; Hinds and Belmain 2022; Pinkham et al. 2022). In

California ground squirrels, the injection of gonadotropin releasing hormone (GnRH) has been over 90% effective at preventing pregnancy for at least 1.5 years (Nash et al. 2004). Oral administration of hormones has the downside of requiring multiple doses, but an advantage to this method, when paired with PIT tag monitoring to ensure individuals get dosed correctly, is that it could be done in a passive, less invasive way (Beatham et al. 2021). Lastly, implants such as levonorgestrel have worked in species such as plateau pika (*Ochotona curzoniae*; Liu et al. 2012) and Mongolian gerbils (*Meriones unguiculatus*; Fu et al. 2013).

Our study had several limitations that affect its management interpretations. One is the lack of replication imposed by a single main capture site and a single release site, which prevents us from knowing how much of the reduced survival of translocated squirrels was caused by the translocation process and how much by the quality of the release site. A second limitation is that translocated squirrels were monitored more frequently than controls, which limited the temporal precision of our survival estimates. A third limitation is large differences in the weather patterns of 2020, a very cool, wet year, and 2021, which exhibited record-breaking heat waves. In other studies of burrowing mammals, weather has been the key indicator of survival probability (Davidson et al. 2014).

In addition to these limitations, refinement of our methods may have yielded different or more robust results. Soil composition, friability, and moisture appear to be particularly important to ground squirrels (Hennessey et al. 2016; Swaisgood et al. 2019) and might have been measured at the capture site and matched at the release site more precisely. A companion study conducted by E. Smith suggested that soil at occupied sites was slightly less sandy (grainy) and more loamy than unoccupied sites (Appendix D). Although we adopted several of the recommended practices to maximize squirrel survival via soft release (Shier 2006; Cid et al. 2014; Tetzlaff et al. 2019), additional measures might better support squirrels. For example, squirrels might have been kept in larger acclimation cages for longer periods of time to reduce their tendency to leave the immediate release site. Predation might have been reduced by building deeper and more connected starter burrows or providing predator-proof burrow chambers, such as those provided to endangered burrowing owls (*Athene cunicularia*; Johnson et al. 2010). Outside of national parks and for species of conservation concern or cultural significance, predation risk might be reduced by predator removal, as has occurred for mule deer (*Odocoileus hemionus*; Cain et al. 2018) and woodland caribou (Hervieux et al. 2014), but those approaches are highly contentious (Harding et al. 2020) and are likely inappropriate for common species. A less contentious approach to predator removal could be the temporary exclusion of predators from the release site via patrol of the site and harassment of predators for a few weeks post-release to allow the squirrels to acclimate and establish better burrow systems (e.g., Shier et al. 2006).

Even with perfect implementation, translocations may not address management goals for Columbian ground squirrels. For example, successful sites for translocating ground squirrels, such as where predators are naturally rare, may position them near people where similar conflict could develop. Additionally, even when translocations are successful at removing an existing colony, recolonization of the original site by conspecifics may occur, such as was recorded for hairy-nosed wombats (O'Brien et al. 2021). In our own study area, resident individuals at Zones B and C (Site 1) moved into the burrow systems that were previously occupied by translocated squirrels. Similarly, conspecific aggression has been observed previously in Columbian ground squirrels (Viblanc et al. 2016) and aggression by residents may have contributed to the departure of translocated squirrels at the release site.

Despite the limitations and potential extensions, our study offers some information relevant to the management of ground squirrels in the mountain parks in future, which we synthesize as three conclusions. First, it appears that even with considerable effort to support translocated squirrels with enclosures, starter burrows, brush piles for cover, and food provisioning, their retention at unfamiliar release sites is low and their survival appeared to be considerably lower than control animals. Retention and survival would undoubtedly have been much worse without these supports. Although Jasper and other national parks have encouraged translocation informally for many years, the survival of these animals is likely very low. For example, we found no burrows and heard no squirrels when we visited a site in July 2021 where a local hotel had previously taken ~30 squirrels that year alone. We suspect that if any of those released squirrels survived, it was because they were able to reach a colony approximately 1 km distant and were accepted at existing burrow systems there. Supported soft-release translocations are time-consuming and expensive (Germano et al. 2015; Tetzlaff et al. 2019) and may not satisfy cost: benefit accounting for abundant species.

A second conclusion from our study is that burrow blocking can deter squirrels from smaller areas if it is undertaken with enough persistence. Additional experimentation with scent and/or chemical deterrents and vegetation adjustment seem worthwhile. The persistent presence of dogs may also be an effective way to deter squirrels without harming them, particularly since several unleashed dogs at our capture site seemed unable to capture and harm squirrels. Instructions for deterrence and encouragement for persistence might address the small-scale conflict that occurs between squirrels and property managers. Reducing the attractiveness of adjacent habitat, especially by eliminating mowed, highly nutritious lawns, is likely to enhance the effects of deterrence.

Finally, many sites that are not occupied by squirrels contain appropriate types and amounts of vegetative forage, but may not contain the right mix of species, the right type of soil, or sufficient protection from predators. The companion study by E. Smith suggested subtle differences in both vegetation and soils at occupied vs. unoccupied sites (Appendix D). Casual observation in and near the Jasper townsite suggests that Columbian ground squirrels are consistently attracted to mowed, fertilized lawns where they may benefit from nutritious new growth, clear vantages for detecting predators, and humans as predator shields. Of these effects, the predator shield may be the most important; for example, a few squirrels quickly colonized an area where trees were removed, but vegetation was sparse and seemingly unsuitable along the major road through the townsite. Preventing ongoing conflict with squirrels will require greater awareness by residents and property managers of the features that attract squirrels. Tolerance for squirrels may be increased by greater awareness of the ecosystem services they offer and the difficulty of translocating them humanely and with high survival.

Tables and Figures

Table 1. A non-exhaustive summary of literature on translocation of ground-dwelling rodents from 1986 to 2022 with a focus on ground squirrel (GS) species. Hard release indicates that animals were given no supports, soft release indicates that animals were contained for some amount of time at minimum.

Author	Year	Species	Sample Size	Location	Supports	Metric	Outcome
Wiggett and Boag	1986	Columbian GS	6	Alberta	Soft release	Survival	All but one juvenile squirrel survived until hibernation and emerged in the spring
Loredo-Prendevilla et al.	1994	California GS	N/A	California	Hard release	Homing, survivorship	Squirrels moved greater than 1500 m did not return home and among those that did not home, two thirds survived.
Van Vuren et al.	1997	California GS	65	California	Hard release	Post-release survival, site fidelity, and homing	Most survived until ~18 days or more after translocation. Mortality was greatest shortly after release and mostly attributed to predation. Most settled away from the release site. Success of homing decreased with increased translocation distance.
Shier et al.	2006	Black-tailed prairie dogs	937	New Mexico	Soft release, predators scared away from site for 1 month post-release, moved with related animals	Fitness of individuals and post-release survival	Animals translocated with family were 5 times more likely to survive, had significantly higher reproductive success, and had lower predation.

Gedeon et al.	2011	European GS	117	Szentendrei Island, Hungary	Soft release, artificial burrows with retention caps	Frequency of recapture	Animals released in the morning and temporarily held in burrows with a retention cap were more frequently recaptured.
Lehrer et al.	2016	Woodchuck	27	Illinois	Hard release	Survival and movement post-release	Translocated woodchucks moved farther than residents immediately post-release but no significant difference in annual survival between translocated and control animals
Hansler et al.	2017	Maritime pocket gopher	15	Texas	Soft release, artificial burrow covered with wire cage	Efficacy of burrowing and homing	Soft released gophers were quicker at burrowing and burying themselves, no homing observed
Koshev et al.	2019	European GS	1730	Bulgaria	Soft release	Survival, settlement, and reproduction	83% of translocations were successful. Success was influenced by the experience of practitioners (and guidelines and research from other practitioners). Success was hindered by poor preparation of the new site, lack of habitat maintenance, and poor weather.
Swaisgood et al.	2019	California GS	707	California	Soft release, artificial burrows, supplemental food, site modification	Survival and movement of squirrels translocated with 3 treatment types (control, mow, mow/auger)	Control squirrel survival fell below 20% within three months. There was no difference in survival between the other two treatments and those individuals were nearly twice as likely to survive than controls.

O'Brien et al.	2022	Hairy-nosed wombats	14 translocated, 13 control	Australia	Hard released into existing burrows	Survival and movement	No mortalities were recorded following release, but nine translocated and nine resident individuals went missing shortly after release. Survival was similar for translocated and resident animals (~54%).

Table 2. Non-exhaustive summary of literature on deterrence of ground-dwelling rodents with a focus on ground squirrel (GS) species.

Author	Year	Species	Sample Size	Location	Methods	Outcome
Lewis et al.	1979	Blacktail prairie dogs	N/A	Oklahoma	1) Forced prairie dogs from burrow systems using water and detergent followed by capture using snares and relocation, 2) R-55 rodent repellent applied to gourds and placed in burrows, 3) asphalt impregnated burlap barriers placed around the burrows	Effective immediate removal of animals when 2-5 burrow entrances were flooded. R-55 repellent use encouraged 17/23 prairie dogs to move. Asphalt-impregnated burlap worked in deterring prairie dogs from burrows, but they moved on to nearby burrows rather than returning to preferred areas. Both repellent and physical/visual barriers (burlap) application required consistent re-application.
Salmon et al.	1987	California GS	127	California	Squirrels removed with live-traps and treatment area burrows were destroyed by digging down 30 cm and loosening the soil in a 30 cm radius to collapse the opening and infill the burrow, then compacting the former burrow to a smooth surface. The area was then mowed, reducing vegetation height to 8 cm and covering the compacted burrow holes with cut vegetation.	The area was eventually (partially) recolonized, and the number of open burrows increased consistently over the active season. The destruction of burrow openings was not adequate in preventing recolonization. Surface burrow destruction in combination with other methods and complete burrow destruction (collapsed to a depth of 60-90 cm) may be more effective.

Gilson and Salmon	1990	California GS and Belding GS	N/A	California	Soil ripping over large area of squirrel burrows using blade (18 in depth) attached to a tractor.	When the population was not adequately controlled first, burrow destruction was much less effective. An integrated pest management (IPM) approach, which uses a variety of approaches (biological, chemical, cultural measures) in conjunction, may work best for GS species.
Loredo-Prendevilla et al.	1994	California GS	N/A	California	Employed live-trapping and translocation (see Table 1) as well as other alternative methods of control such as	Translocation is not always an option. Heavy-gauge wire laid on the ground may reduce burrowing activities. Other habitat alterations include ripping up burrows (as shown in Gilson and Salmon above) and planting dense, low-growing vegetation but it is important to reduce as much adjacent open habitat as possible in conjunction with this method. Predator supplementation may be appropriate in some areas. Similarly, sterilization of GS will reduce population sizes over time but will not remove current residents. An integrated approach of multiple methods might be best in some areas. Lastly, where the cost of reducing population densities outweighs the benefits, no action may be the best option.
DeLiberto et al.	2018	Richardson's GS	30	Montana	Anthraquinone repellent applied to a structural barrier. Efficacy tested by determining failure rates of attempts to defeat the structural barrier	Relative to untreated barriers, the treatment reduced defeat of the barrier by 50-55%.

Table 3. Details of Columbian ground squirrels that were monitored in Jasper National Park, Alberta, Canada, in 2020 and 2021.

Source location	Cohort	Translocation date	Sample size	Age class[a]	Females	Males
Translocated						
Site 1	1	20 July 2020	6	Juveniles	2	1
				Adults	1	2
				Total	3	3
	1	25 July 2020	11	Juveniles	2	3
				Adults	2	2
				Total	4	5
	2	10 May 2021	3	Juveniles	0	0
				Adults	3	0
				Total	3	0
	2	14 May 2021	3	Juveniles	0	0
				Adults	2	1
				Total	2	1
	2	July 26* 2021	7	Juveniles	2	1
				Adults	3	1
				Total	5	2
Site 3	2	July 23 2021	3	Juveniles	1	1
				Adults	1	0
				Total	2	1
Control						
Site 1	1			Juveniles	3	1
				Adults	3	5
				Total	6	6

	2	Juveniles	1	1
		Adults	3	5
		Total	4	6
Site 2	2	Juveniles	0	4
		Adults	2	2
		Total	2	6

*-one juvenile squirrel was translocated later on August 8 due to failure to capture it with its mother.

a- juveniles were < 1 year and adults were > 1 year; yearlings were categorized with adults due to the inability to separate them beyond a certain weight (Boag and Murie 1981)

Table 4. Annual survival rates (S(t)) for translocated and resident Columbian ground squirrels in Jasper National Park, Alberta, Canada, 2020-2022. Superscripts indicate significant differences* in survival rates between translocated and control groups.

Group	0-365 days	
	S(t)	95% CI
Translocated (overall)	0.087^{A}	0.024 - 0.310
Cohort 1	0.00^{B}	
Cohort 2	0.208^{C}	0.071 - 0.614
Control (overall)	0.752^{A}	0.606 - 0.933
Cohort 1	0.833^{B}	0.108 - 0.647
Cohort 2	0.722^{C}	0.542 - 0.962

* log-rank $\chi^2 > 10.82$, $p < 0.001$ for AB and log-rank $\chi^2 > 3.84$, $p < 0.05$ for C

Table 5. Top-ranked candidate models predicting re-entry probability. Dependent variables were modeled with a binomial distribution and ranked using Akaike Information Criterion (AIC). Model coefficients are shown at right with the comparator category in parentheses.

Model terms	**df**	**Weight**	**ΔAIC**	Coefficients (95 % CI)	
Intercept only	1	0.30	0	Block Type (Stake)	-3.80 (-2.2 – 0.020)
Block type	3	0.24	0.39	Spray (Yes)	-0.11 (-1.1 – 0.86)
Spray	3	0.16	1.25	Block * Spray	1.1 (-0.42 – 2.57)
Block Type + Spray + Block Type * Spray	5	0.15	1.32		
Block Type + Spray	4	0.15	1.42		

Figure 1. Study sites in Jasper National Park. Site 1, which was a 1.5 ha area located immediately north of the Forest Park Hotel where a new police detachment is to be built had squirrels and burrows that were used for the translocation and deterrence experiments, respectively. Site 2 was a 1.5 ha area approximately 1.5 km north of Site 1 in an open meadow that began ~200 m north of the Jasper municipal cemetery where we moved all of the translocated ground squirrels. Site 3 was a 0.20 ha area east of Connaught Drive between Willow and Hazel Avenues where a municipal waterline was installed in September 2021 for which squirrels needed to be removed in advance. Site 4 was located at the Palisades Education Centre about 10 km from the Jasper townsite.

Figure 2. Zones of study Site 1. Located north of the Forest Park Hotel in the Jasper townsite of Jasper National Park, Site 1 contained Zone A (blue) which was occupied by Columbian ground squirrels that were translocated across 2 seasons spanning between 2020 and 2021, it was later surrounded by a fence to reduce recolonization (white border within Zone A); Zone B (red) which contained ground squirrel burrows that were used in the burrow blocking deterrence experiment; and Zone C (green) which was occupied by squirrels that were not translocated or deterred from their burrows to be used as controls.

Figure 3. Images of Site 1. The first image is facing north from the center of the site, the second image is facing southeast from the center of the site. Site 1, which was located immediately north of the Forest Park Hotel, was formerly sparsely treed but was deforested in 2017-2018 as part of the fire prevention program and was later cleared more extensively to permit construction. It contained a section to the north that were partially treed (Zone C) and sections to the south that were composed of a mix of grasses, forbs, shrubs, and stumps from the previous clearing activities (Zones A and B).

Figure 4. Images of Site 2 facing northwest and northeast. Site 2, which was located immediately north of the Jasper municipal cemetery, and approximately 1.5 km from Site 1, was a large, apparently homogeneous, native grassland with moderate productivity typical of mesic grasslands. Along the western edge of the grassland, there were some shrubs and rocks, including ballast rock from an adjacent railway. The top image shows a temporary enclosure used to acclimate the squirrels to the new site to reduce the likelihood of immediate dispersal

upon release, one of the Tomahawk live traps used to capture squirrels, artificial burrows and associate slash piles (slash piles also visible in the bottom image), small lengths of tube used to supplementally feed translocated squirrels, and an RFID reader (PIT) and its associated antenna in the middle of the image (black tool box).

Figure 5. 116 burrows were blocked and monitored daily at Site 1. Columbian ground squirrel burrows blocked with either pool noodles or wooden stakes and monitored daily for activity from 10 May to 9 June 2022 in Zone B of Site 1.

Figure 6. 63 burrows were blocked and monitored near daily at Site 4. Columbian ground squirrel burrows blocked with wooden stakes and covered with wire mesh and monitored near daily for activity between 13 July and 31 August 2021 at the Palisades Education Centre (Site 4).

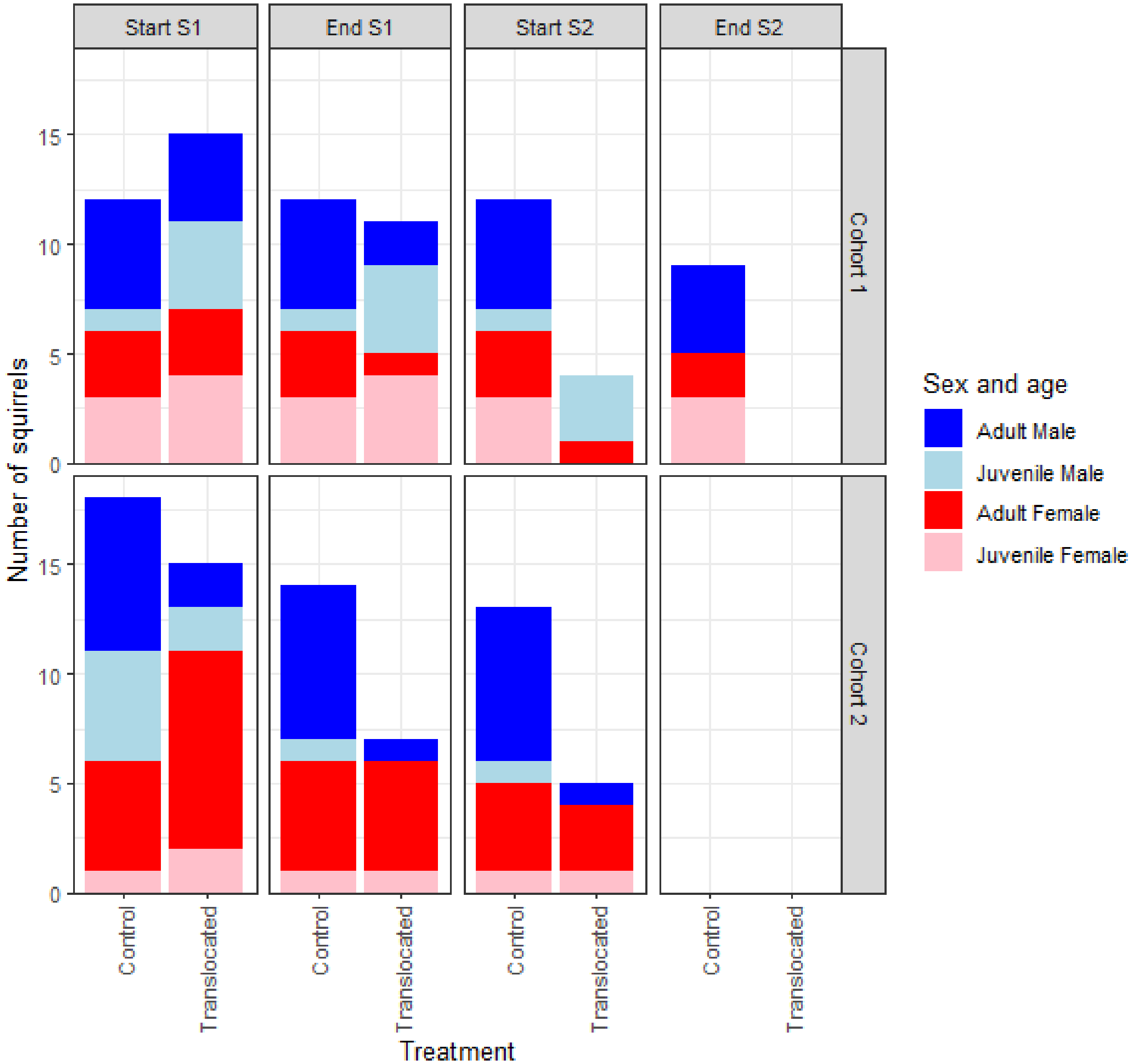

Figure 7. The number of translocated and control squirrels that were detected through their first and second season of monitoring between 16 June 2020 and 26 May 2022. Bars are separated by cohort (Cohort 1 was monitored through 2020-2021, Cohort 2 was monitored through 2021-2022) treatment (translocated or control), age (adult being more than 1 year old and juvenile being less than 1 year old), and sex (male or female).

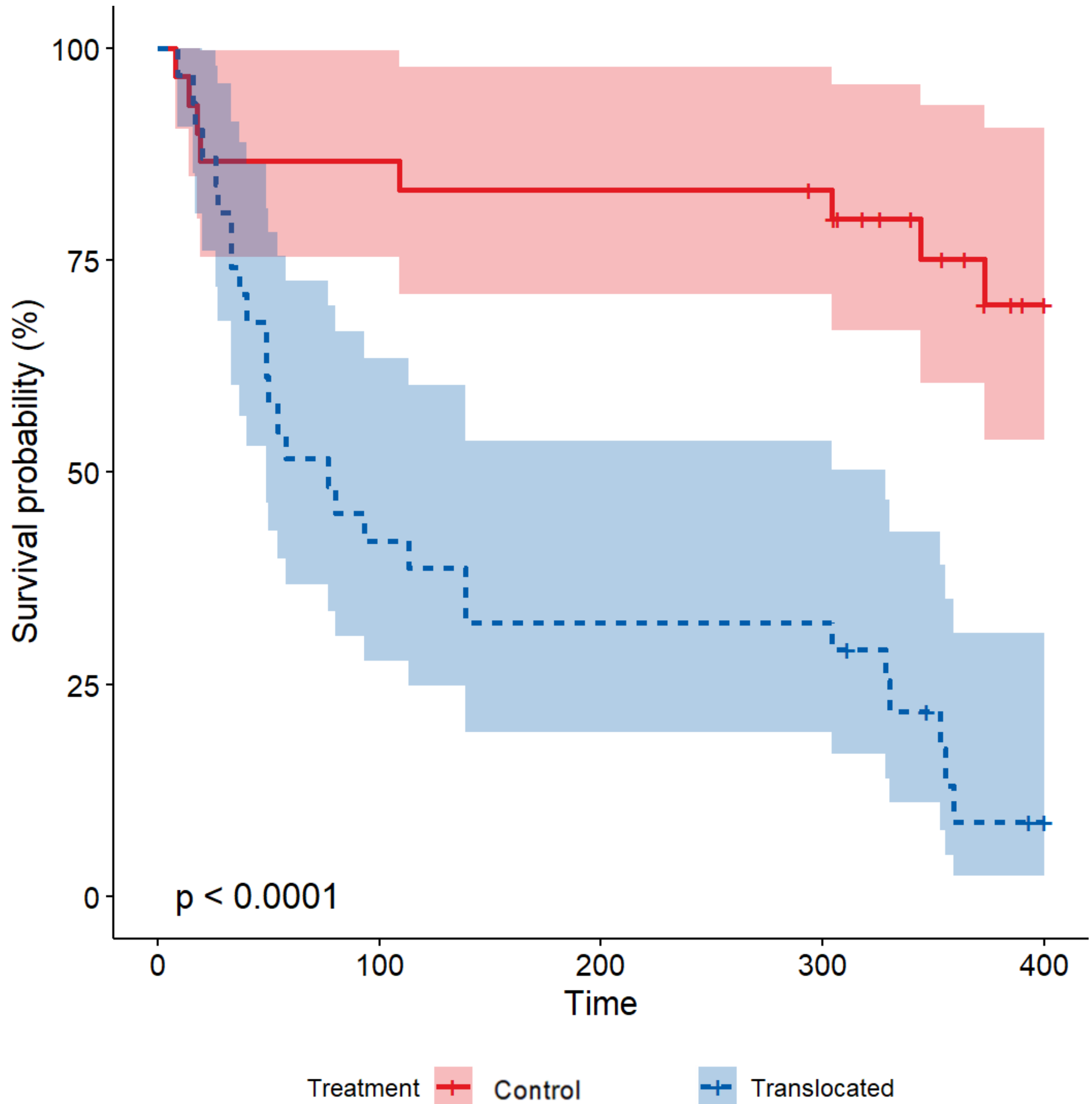

Figure 8. Kaplan-Meier survival curves for translocated and control Columbian ground squirrels in Jasper National Park, Alberta, Canada over 400 days from the dates on which translocations occurred in 2020 and 2021.

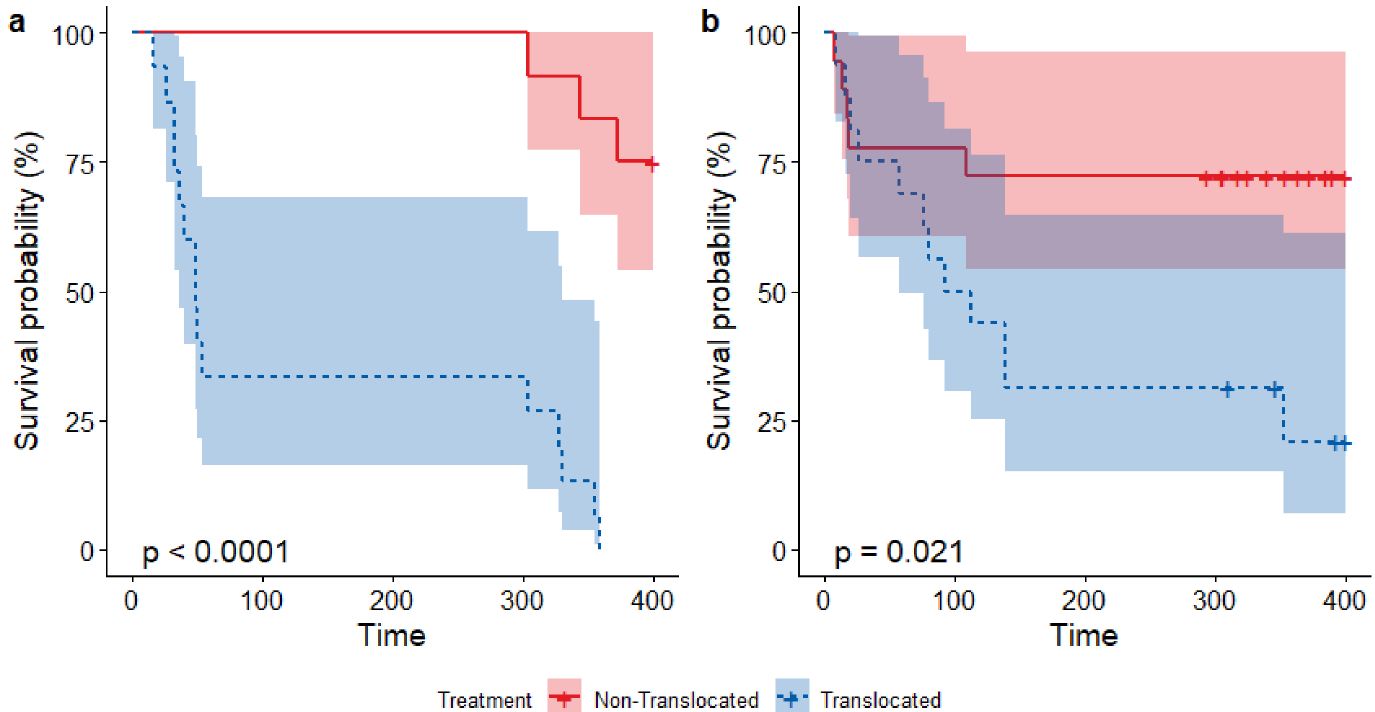

Figure 9. Kaplan-Meier survival curves for translocated and control Columbian ground squirrels over 400 days from Cohort 1 (a) and Cohort 2 (b), which included squirrels that were captured and translocated in 2020 and 2021, respectively in Jasper National Park, Alberta, Canada.

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Appendix A

Site selection and burrow maps

M. Bradley

Figure 1. Map of burrows at Site 1 showing occupied zones (purple) and unoccupied zones (black). Map created 4 May 2020 in preparation of the 2020 field season.

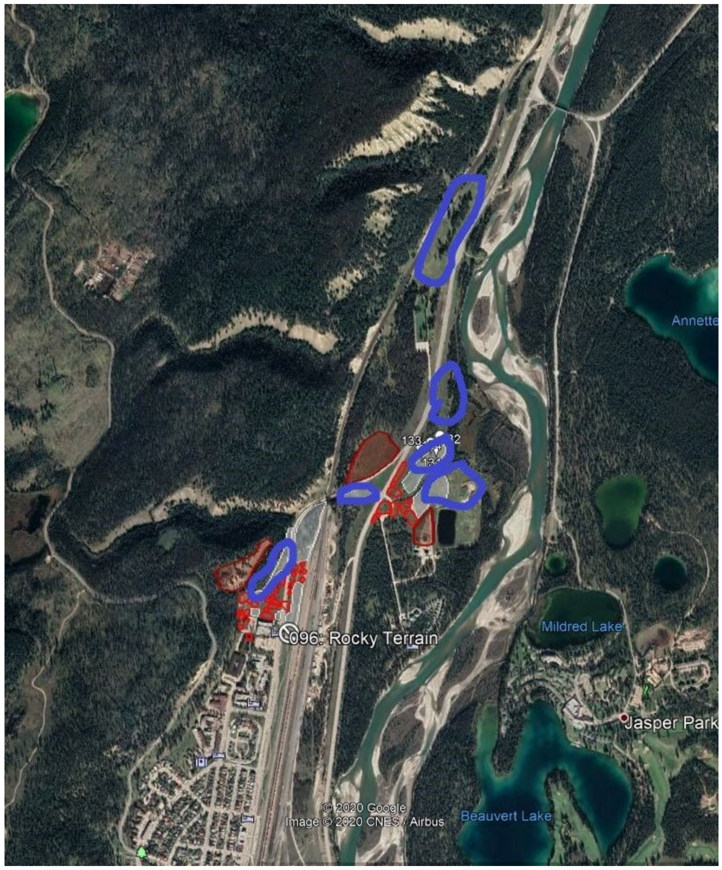

Figure 2. Overview of potential release sites surveyed in May 2020. Sites identified as possible release sites outside of municipal jurisdiction and appeared to have suitable vegetation as identified by M. Bradley.

Figure 3. Non-viable release site 1 northeast of the area from which squirrels were removed**.** Area considered as possible release site for a single coterie (family unit) of squirrels. The site was determined to be both too small and too close to the capture area.

Figure 4. Non-viable release site 2 northwest of the area from which squirrels were removed**.** Similar to Figure 3, the area was considered non-viable due to its small size and close proximity to the capture site.

Figure 5 Non-viable release site 3 northwest of the area from which squirrels were removed. Similar to Figure 3,

the area was considered non-viable due to its small size and close proximity to the capture site.

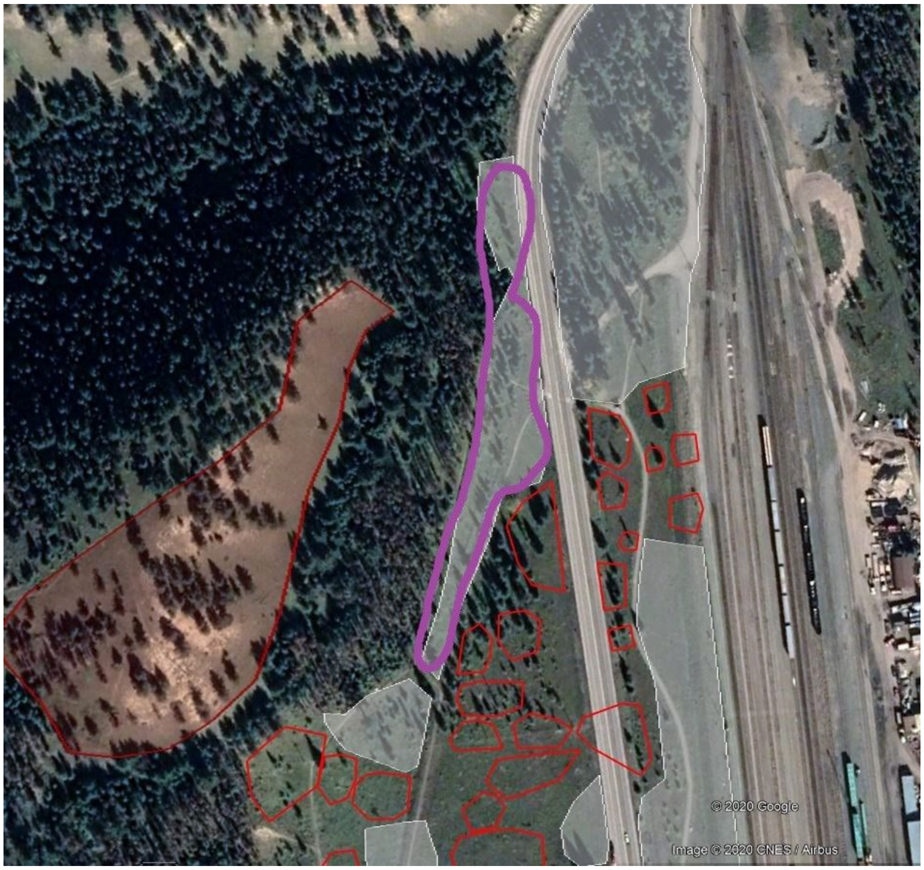

Figure 6. Non-viable release site 4 north of the area from which squirrels were removed**.** The site was previously cleared to reduce fuel load in the case of a forest fire and appeared to have past and present squirrel activity. Similar to the previous two sites, it was deemed too close to the capture site for translocation.

Figure 7. Non-viable release sites north of the area from which squirrels were removed**.** These sites were deemed non-viable because they were difficult to access and current population sizes could not be easily identified. Accessing sites was an important consideration to reduce the time translocated squirrels had to be contained to reduce health risks

Figure 8. Selected release site north of the Jasper municipal cemetery**.** This site was selected because it resembled the site from which squirrels were removed (similar vegetation, walking trail nearby), had signs of past and present squirrel activity, was almost entirely accessible by vehicle, and was more than 1 km away from the capture site to discourage homing.

Appendix B

Field protocol for the translocation of Columbian ground squirrels (*Urocitellus columbianus*) in the Canadian Mountain Parks

Prepared by Brianna Lorentz, Gabrielle Lajeunesse, and Colleen Cassady St. Clair, Last updated: 5 August 2022

Preamble

In areas where excavation is needed for infrastructure development, the removal of Columbian ground squirrels (*Urocitellus columbianus*) may be required. Columbian ground squirrels are a semi-fossorial mammal that create burrow systems underground and forage above ground for vegetation. Translocation, which is the deliberate movement of animals from one location to another by humans, may be appropriate in these areas where lethal measures are not favoured. This document is meant to serve as a standard protocol for the translocation of this species.

Selecting and preparing the release site

1. Select a suitable release site based on three criteria: the soil type, the vegetation height and type, and signs of past or current squirrel activity. The soil should be fine textured, well drained, and friable (i.e., will crumble easily)[1]. It should contain little gravel and have a low clay and silt content[2]. The vegetation should be less than 30cm tall and forbs should be the main vegetation type[3]. A site presenting signs of past or current squirrel activity (burrow holes and visible runs between holes) should be favored[1]. To deter homing, select a release site that is over one kilometer away from the original site, if possible (see *Deterring ground squirrels from exclusion zone* for additional exclusion methods).
2. Estimate the number of squirrels needing to be relocated.
3. If necessary, use a sharp ended digging pole in an area where you intend on digging. Remove or move to the side all the rocks that could be in the auger's way.
4. Using a soil auger with a 3' bit, dig four 1m deep[4] burrows at a 45° angle[5] per squirrel. (Figure 1). Two of these burrows should only have one entrance and the two other burrows should have two entrances. Create the second entrance by digging an intersecting hole, also at a 45° angle from the surface, 1.41m away from the first burrow.

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[1] Roe, K.A., Roe, C. M. 2003. Habitat selection guidelines for black-tailed prairie dog relocation. WILDLIFE SOCIETY BULLETIN 31(4): 1246-1253

[2] Swaisgood, R. R., Montagne, J.-P., Lenihan, C. M., Wisinski, C. L., Nordstrom, L. A., Shier, D. M. 2019. Capturing pests and releasing ecosystem engineers: translocation of common but diminished species to re-establish ecological roles. ANIMAL CONSERVATION 22(6): 600-610

[3] Gedeon, C. I., Boross, G., Nemeth, A., Altbacker, V. 2011. Release site manipulation to favour European ground squirrel *Spermophilus citellus* translocations: translocation and habitat manipulation. WILDLIFE BIOLOGY 18(1): 97-104

[4] Truett, J. C., Savage, T. 1998. Reintroducing prairie dogs into desert grasslands. RESTORATION AND MANAGEMENT NOTES 16(2): 189-195; Gadd, B. 2016. Handbook of the Canadian Rockies. CORAX PRESS fifth printing of the second edition 832 pp.

[5] Dullum, J. A., Foresman, K. R., Matchett, M. R. 2005. Efficacy of translocation for restoring populations of black-tailed prairie dogs. WILDLIFE SOCIETY BULLETIN 33(3): 842-850; Swaisgood, R. R., Montagne, J.-P., Lenihan, C. M., Wisinski, C. L., Nordstrom, L. A., Shier, D. M. 2019. Capturing pests and releasing ecosystem engineers: translocation of common but diminished species to re-establish ecological roles. ANIMAL CONSERVATION 22(6): 600-610; Truett, J. C., Savage, T. 1998. Reintroducing prairie dogs into desert grasslands. RESTORATION AND MANAGEMENT NOTES 16(2): 189-195

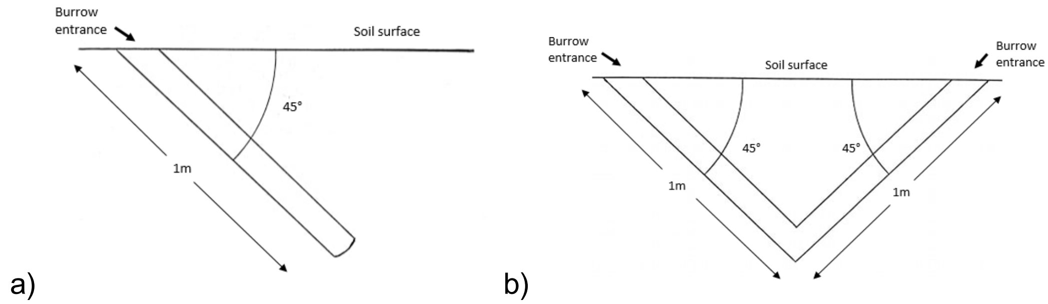

Figure 1. a) an example of a 1m long one entrance burrow dug at a 45° angle b) an example of a two entrances burrow.

5. Add several additional holes around the release plot (about 20 per area) to achieve a density of approximately one hole every $10m^2$. [6]
6. Add fertilizer to the release site to stimulate forb growth (optional).
7. Mark out release plots on the periphery of current squirrel activity. Aim to have enough space for all relocated individuals (breeding female home ranges average around 400- 500 m^2). [7]
8. Create a secure enclosure large enough for the squirrel to move around in. Use small gauge rolled fencing for the sides (¼- ½ inch) to ensure squirrels do not get stuck (figure 2).
9. Relocate multiple squirrels as a group whenever possible to increase likelihood of survival[8]. While trapping and observing prior to moving, determine squirrels that group together (trapped at the same times in the same places, often seen showing affiliative behaviours to one another) and place them close together on release site. Wait until multiple squirrels have been trapped and processed before releasing them, in order to make sure squirrels are never by themselves on the release site. Place release plots in patterns comparable to the capture sites.
10. If available, add a wildlife camera to monitor squirrel activity at each release plot. Auger a vertical hole on the south side of each release plot. Put a 4x4 post in the hole and insert a deep eye hook at waist height. Attach a wildlife camera to the post, facing North, and secure it to the eye hook with a Python lock. Supplement or replace camera-based monitoring with visual observations daily and record the amount of time spent monitoring for activity.

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[6] Hennessy SM, Deutschman DH, Shier DM, Nordstrom LA, Lenihan C, Montagne J-P, Wisinski CL, Swaisgood RR. 2016. Experimental habitat restoration for conserved species using ecosystem engineers and vegetation management. Animal Conservation. 19(6):506–514. doi:10.1111/acv.12266.

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[8] Shier, D. M. 2006. Effect of family support on the success of translocated black-tailed prairie dogs. CONSERVATION BIOLOGY 20(6): 1780-1790

Figure 2. Enclosures used for temporary containment of translocated squirrels. A 1 m by 1 m wooden frame wrapped in ¼ in hardware mesh fencing with a plastic-coated wire bottom and corrugated plastic top hinged in the middle to allow one side to open.

Mapping existing burrows

If squirrels are to be removed from a large site, survey and map existing burrows at both the build site and release sites.

1. Using coloured pin flags, establish a 10x10 m grid labelled with letters (for rows or latitude) and numbers (for columns or longitude). Label burrows as they are encountered in relation to the flag to the south and east of the Use flags as the (i.e., a burrow may fall in section A1 and will then be labeled as A1.1 and so on) in the exclusion zone.
2. Take a photo of the set up for future reference.
3. Using a GPS unit, mark all the squirrel holes in the exclusion zone and number them according to their grid label. Mark each burrow 3 times and average the readings to achieve higher GPS accuracy.
4. Record the UTM of each burrow plot location on a GIS platform if desired.

Conditioning the squirrels

Traps

1. Wire traps in the open position using short sections of wire or small s hooks.
2. Several times a day, apply a few milliliters of sweetened peanut butter on the trap treadle. Repeat this process as necessary until squirrels are removing peanut butter regularly.
3. Make note of any observed latency to enter traps and when squirrels are observed inside of the trap.

PVC tubes

1. Place PVC tubes around the capture site with a few ml of peanut butter.
2. Repeat this process several times a day and make note of any latency to enter the tubes.

Trapping the squirrels

1. Determine if it is the right time of the year to relocate the squirrels (Figure 3). Females typically emerge a few days after the males and can be trapped during the last two weeks of April and the first two weeks of May, as well as at the end of July.

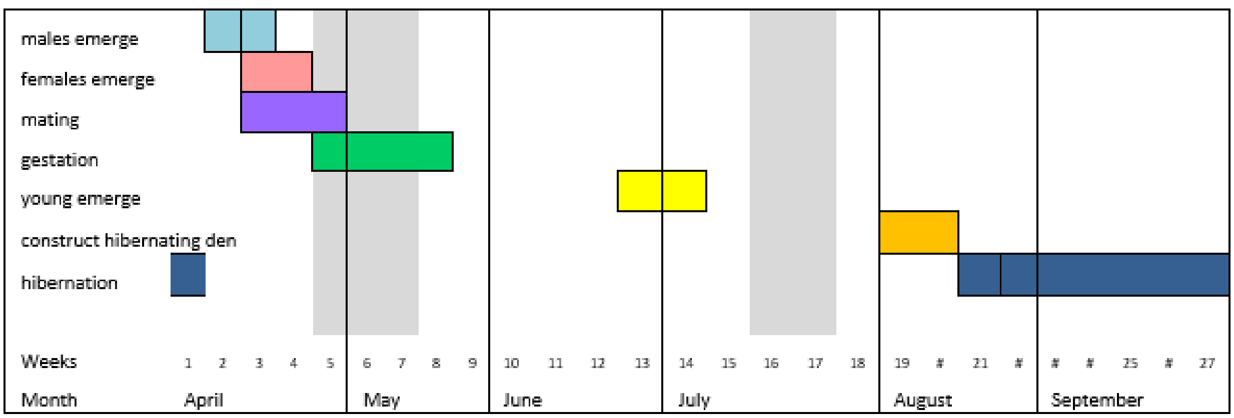

Figure 3. Approximate timing of squirrel life history[9] indicating windows (in gray bars) when females can be translocated without likely impact on reproductive success. Figure created by M. Bradley.

2. Trapping should ideally take place in the morning; however, other times of the day may be used if the temperature does not exceed 25° C and there is no heavy precipitation.
3. No more than 40 traps should be operating at a time.
4. Attach corrugated plastic covers to the top of the traps to protect squirrels from sun and minor precipitation.
5. Bait the traps by putting a few milliliters of sweetened peanut butter on the treadle.

[9] Murie, J. O., Haris, M. A. 1982. Annual variation in spring emergence and breeding in Columbian ground squirrels (Spermophilus columbianus). JOURNAL OF MAMMALOGY 63:431-439

6. Set the traps by pushing in the safety door, pulling up the door and pulling the trigger hook forward. Test the trap to make sure that the door will close if the animal steps on the treadle and adjust the treadle wire to achieve action with a light weight. Creating a downward bend in the wire makes it harder to trip.
7. Check the traps every 40 minutes if the temperature is under 20°C, or every 30 minutes if the temperature is above 20°C. **Do not trap** if the temperature exceeds 25°C or if it rains to avoid risk of hyperthermia or hypothermia.
8. Try to capture one coterie (group of squirrels) for relocation at a time, if possible. This can be determined by observing the squirrels' social activities or with the use of passive monitoring techniques like RFID tags and readers.
9. If a squirrel shows signs of heat stress or extreme reactions to being trapped (drooling, panting), place the squirrel in a trap covered with a pillow case in a cool, shady spot before handling it. If the squirrel continues to exhibit distress, release the animal at the site where it was trapped and do not handle it.

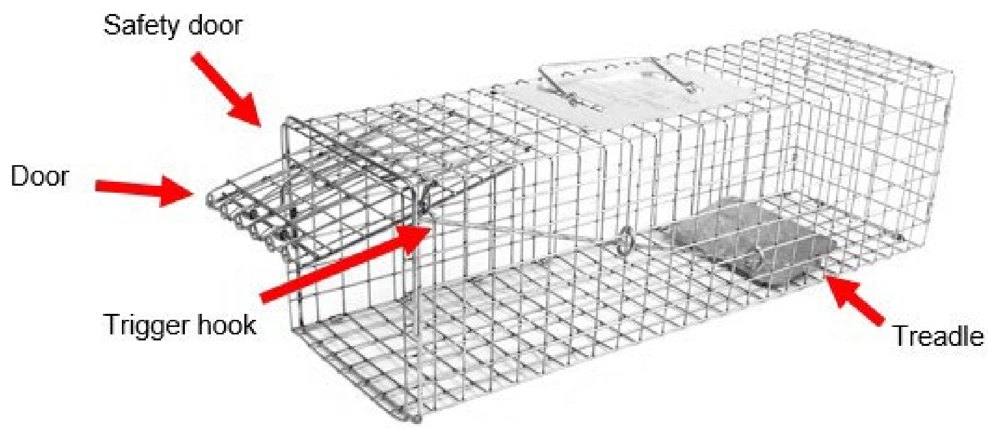

Figure 4. The location of the safety door, the door, the trigger hook and the treadle are indicated by a red arrow on this Tomahawk live trap

Manipulating the squirrels

1. Wear a leather glove thin enough to feel the animal, but thick enough to withstand bites.
   a. COVID19 precaution: wear latex or nitrile gloves and masks while handling squirrels.
2. Approach the trap slowly and record the squirrel's activity and vocalizations on the field data sheet provided.
3. If you need to carry the trap elsewhere, cover it completely with cloth to create a calming, dark environment.
4. Put a pillowcase (or trapping bag) over one end of the trap and open the trap's door so that the squirrel runs into the trapping bag (Figure 5). If the squirrel does not run into the pillow case, gently tap on the back of the trap. You can also blow on the squirrel or tip the trap. Record the animal's escape response.

Figure 5. Moving squirrels from trap to trapping bag.

Handling, measurements and marking

1. Keeping the squirrel in the pillowcase, weigh the squirrel using an electronic balance. Record the squirrel's weight. Subtract the weight of the pillow case from the squirrel's weight later.
2. Guide the squirrel to the corner of the pillow case to reveal its torso. Grip the squirrel around its neck and front legs by placing your index and middle finger on either side of the animal's head and your thumb and ring finger behind the forelegs. Refer to Figure 6 for more information.

3.

Figure 6. Columbian ground squirrel being appropriately held using the "squirrel grip" technique.

4. Record if the squirrel tries to scratch the researcher with his hindlegs while being held.
5. Determine and record the squirrel's sex and breeding condition (Figure 7). The anogenital distance is shorter for females than for males. A female's breeding condition can be determined by a visible swelling of her vaginal opening, indicating that she is in oestrus, the presence of a copulatory plug, indicating that she has recently mated, or the presence of chickpea shaped lumps when lightly palpating the female's abdomen, indicating that the female is pregnant. (https://adventuretup.wordpress.com/2016/05/05/squirrel-vaginas-trust-me-its-science/)

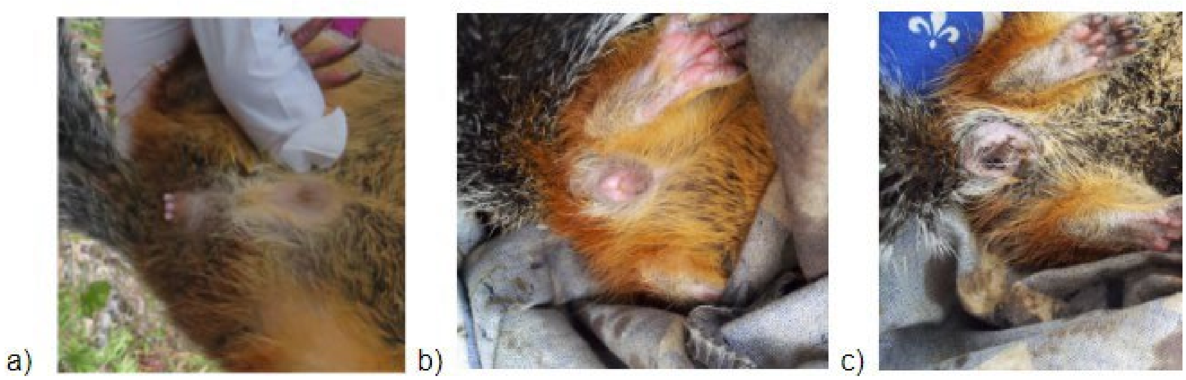

Figure 7. a) a male Columbian ground squirrel b) a female Columbian ground squirrel in oestrus, with visible swelling to the vaginal opening c) a female Ground squirrel with a brown copulatory plug

6. Ear tagging: attach a numbered metal ear tag to both ears using the pliers. Be sure to attach the tag in the pinna of the ear in the approximate middle, before the very thin skin of the ventral section (Figure 8). Place pliers so that the fold in the tag is flush with the

outer flap of skin. Tags that are inserted too deeply, folding the skin, cause infection. Tags that are too shallow tear the pinna and fall out. Record the ear tag number.

a)

b)

Figure 8. a) attaching ear tag with pliers b) attached ear tag

7. PIT tagging: Attach a PIT tag receiver fitted with a small ruler to the end of a PVC tube at the processing site, and pass PIT tags loaded in needles through the receiver to test their reading distance. Note any tags that need to be closer than 5 cm to be read and discard any that cannot be read. Clean the implant site with an alcohol swab. Using a 12-gauge needle, insert the pit tag between the squirrel's shoulder blades while pinching the scruff (Figure 9). The needle should be bathed in 70% Ethyl Alcohol after each use and may only be used a total of **nine** times. Note the PIT tag identification number and when the needle was last changed.

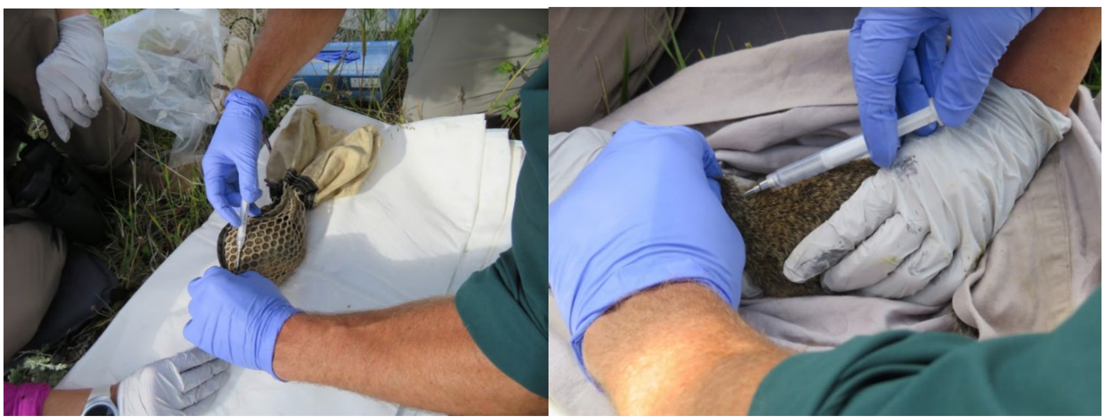

Figure 9. Team properly inserting a PIT tag between a squirrel's shoulder blades

8. Dye marking: Using Clairol Nice 'N Easy black semi-permanent hair dye, apply a unique mark to the ventral side of the squirrel with a fine brush. Avoid pressing the dye directly against the skin to prevent irritation. Avoid smudging the dye with the pillow case or your hands as the squirrel is released back into the trap for transport to its new burrow. Record the dye mark placement.
9. Radio-collaring: attach the collar over the squirrel's head and cinch the zip tie until you can only fit the full lead of a wooden pencil between the collar and the animal's neck. A collar too tight could lead to skin abrasions, while a collar too loose could lead to a slipped collar or strangulation. Only tag animals weighing over 300g.
10. Collect fecal pellets from around burrows and label them, these will be transported with the squirrels to the release site to act as familiar scent cues.
11. Fresh fecal pellets should also be collected from the trap itself and from the material on which they are processed, ensure that they have not been in contact with urine. Immediately place fresh pellets into tubes, label them with the date, squirrel ID, and lab identification before placing them into an insulated bag filled with ice packs. These samples will be moved to a freezer at the end of the field day.

<u>**Note**</u>

Transfer monitoring records to an electronic spreadsheet at the end of every trapping day.

Releasing the squirrels on the selected release site

1. Assign each coterie to a specific location on the release site so that a group of squirrels from the same capture site stay together.
2. Set up the release plot by securing the wildlife camera to a post driven into the ground in the south end of the plot.
3. Set up the enclosure and place a PVC tube with a small bit of the feeding mixture spread inside towards the middle of the tube into the enclosure.
4. Place the squirrel into the enclosure.
5. Add fresh food daily. Provide the squirrels with food in the form of organic peanut butter, food pellets (rabbit food) rabbit food, fresh greens, shredded sweet potatoes, and apple slices[10].
6. After 3 days (up to a week), open the soft-release enclosure but consider leaving it in place for another week or more as a refugium.

Monitoring the squirrels

1. Regular observations of the relocated squirrels help us to understand their post-release survival.
2. Record any attempts by squirrels to return to the exclusion zone and any supplementary trapping required.
3. Make note of the location the squirrel was observed, the condition of its markings, status (alive or deceased), general body condition (e.g., healthy, missing fur, etc.), whether or not it has young, and of the behaviour it is exhibiting (e.g. sitting, standing, digging, vocalizations).
4. Monitor the squirrels after release to determine retention at the site using one or more of the following: VHF, RFID, mark-recapture.

Deterring squirrels from exclusion zone

1. Plug all burrow holes using construction stakes and hardware mesh.
2. If possible, destroy burrow systems to deter recolonization altogether.
3. Monitor the burrows each day looking for signs of activity: tracks, scat, digging, displacement of blocking implements, or removal of blocking implements.
4. Block any new holes and continue spraying until the squirrels stop trying to use the burrows.

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[10] Truett, J. C., Savage, T. 1998. Reintroducing prairie dogs into desert grasslands. RESTORATION AND MANAGEMENT NOTES 16(2): 189-195; Wigget, D.R., Boag, D.A. 1986. Establishing colonies of ground squirrels during their active season. WILDLIFE SOCIETY BULLETIN 14(3): 288-291

Euthanizing the squirrels

Euthanasia procedure developed in accordance with the University of Alberta Animal Care Committee and the Canadian Council on Animal Care. Euthanasia system built following example in Wilksinson 2017 (unpublished; Figure 10) and flow rates were designated using the Carbon Dioxide Euthanasia procedure from the University of British Columbia (2008).

1. Connect the CO2 cartridge to the pressure regulator and to the hose.
2. Remove the lid from the euthanasia chamber. Place the squirrel inside the euthanasia chamber. Put the lid back on the container and make sure the container is sealed.
3. Turn on the regulator to the psi level require to obtain a flow rate between 20-30% of the chamber per minute.
4. Observe the animal until it stops moving, responding to stimuli or breathing. This should take approximately 5 minutes.
5. Wait another minute from the time the animal took its last breath before turning off the flow of CO2.
6. Remove the animal from the container and examine it for signs of life. If signs of life are detected, place the animal back inside the euthanasia chamber and repeat the protocol from step 3.
7. If there are no signs of life, apply a secondary method of euthanasia.

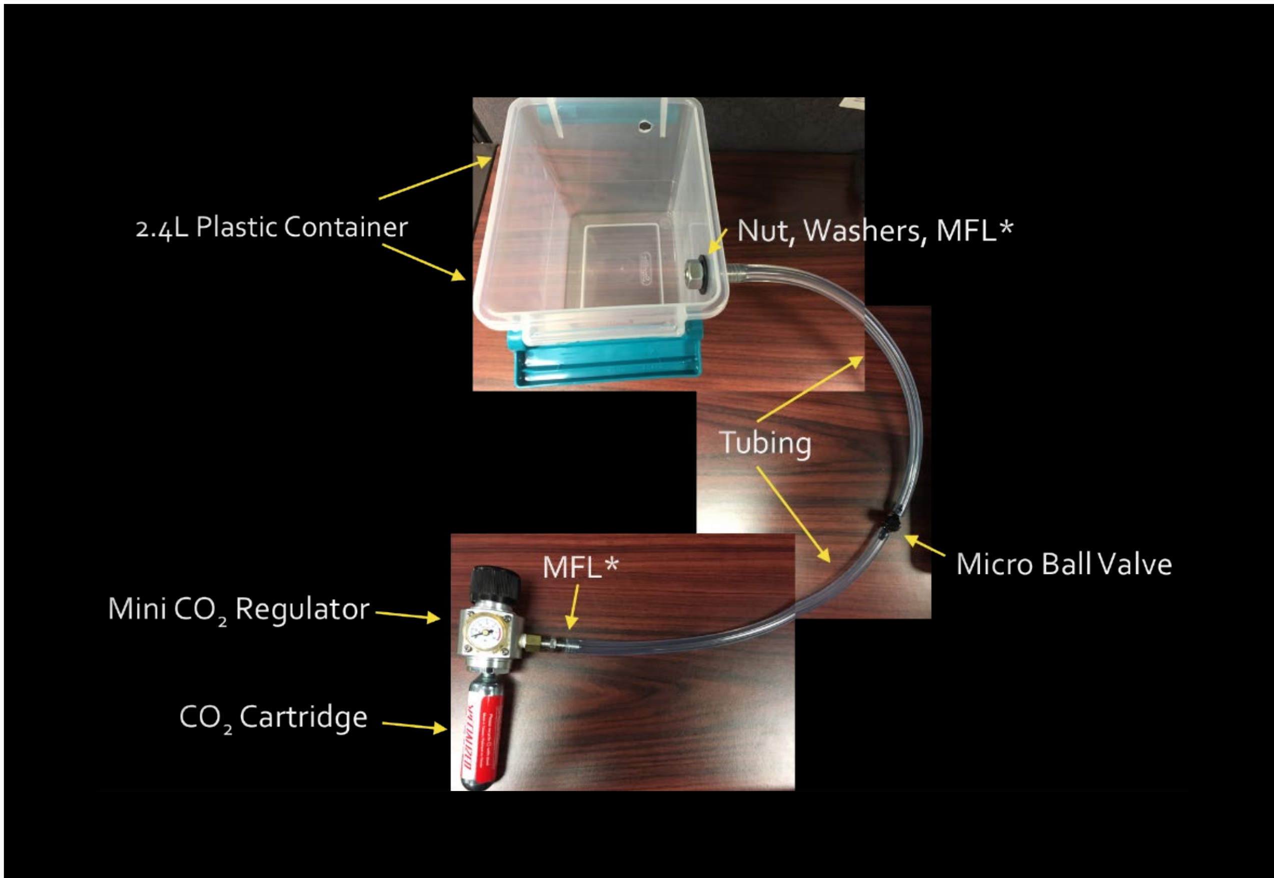

Figure 10. CO2 Euthanasia chamber example from Wilkinson 2017. The chamber is a modified plastic container that must be big enough to accommodate the animal. Inflow and outflow holes are drilled into the walls of the container and tubes are secured with nuts and washers. A CO2 regulator/flow meter must be attached to ensure the flow rate is appropriate for the species.

Appendix C - Identification and Longevity of Marked Individuals

Table 1. Identification and longevity information for 107 squirrels captured in Jasper National Parks between 17 June 2020 and 25 May 2022. Ear tags are given for left then right ear, sex is male (M) or female (F), age at first capture is adult (A), yearling (Y) or juvenile (J). Location of first capture is given as Site 1, which was north of the Forest Park Hotel in the Jasper townsite (1); Site 3, which was the area east of Connaught Drive between Willow and Hazel Avenues in the Jasper townsite (3); or Site 2, which was the area ~1.5 km north of Site 1 (2). The first capture is via trapping and last detection is via capture (C), PIT tag (P), Visual (V) or telemetry (T).

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
I	039-811-890	766	751	F	A	17-Jun-20	1	17-Apr-21	T
Infinity	039-884-335	359	360	M	J	18-Jul-20	1	13-Jun-21	P
Y	039-887-047	363	364	M	J	25-Jul-20	1	11-Aug-20	P
Heart	039-849-099	342	343	F	J	09-Jul-20	1	11-Aug-20	P
Star	039-560-873	344	345	F	J	09-Jul-20	1	11-Aug-20	P
V 2 dot	040-011-291	771	755	F	A	17-Jun-20	1	24-Jul-20	T
=	039-857-635	774	775	F	J	22-Jun-20	1	11-Aug-20	P
One dot	039-871-602	776	777	F	J	23-Jun-20	1	11-Aug-20	P
S	039-882-599	772	773	M	J	21-Jun-20	1	11-Jun-21	P
H	040-010-260	778	779	M	J	23-Jun-20	1	17-Jun-21	P
O	039-800-261	768	769	M	A	19-Jun-20	1	07-Aug-20	T
X	040-043-067	762	763	M	A	18-Jun-20	1	11-Aug-20	V
H 2 dot	039-558-299	780	754	F	A	17-Jun-20	1	27-Jul-20	P
Dash	039-875-870	757	756	M	A	17-Jun-20	1	11-May-21	P
Tripod	039-839-780	788	789	M	A	27-Jun-20	1	24-Jul-20	T

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
A	039-621-636	346	347	F	A	09-Jul-20	1	25-May-22	P
Shoulders	040-011-267	753	361	F	Y	17-Jun-20	1	23-Jun-21	P
Z	039-869-010	781	782	F	Y	25-Jun-20	1	01-Jun-21	T
V	039-382-367	355	356	M	A	12-Jul-20	1	06-Jul-21	T
Stripe	039-614-047	752	770	F	A	17-Jun-20	1	21-Aug	V
V 3 dot	039-591-546	760	761	F	A	17-Jun-20	1	20-Jun-21	P
Squig	041-110-318	216	217	F	A	12-Jun-21	3	25-May-22	P
Little squiggle	041-259-326	203	204	F	J	07-Jul-21	3	27-Jul-21	P
Wave		249	250	M	J	19-Jul-21	3	04-Aug-21	P
NN		348	349	M	A	14-May-21	1	21-Aug-21	T
3	039-595-008	798	799	F	Y	30-Jun-20	1	26-Jul-21	T
Trident	040-027-054	365	366	F	Y	29-Jul-20	1	21-Aug-21	T
RC	039-881-878	304	305	F	A	27-Apr-21	1	25-May-22	P
FHC	041-065-888	237	238	F	J	17-Jul-21	1	24-May-22	P
HCL	040-790-376	239	240	M	J	20-Jul-21	1	15-Aug-21	P
HC	041-271-879	247	248	F	J	17-Jul-21	1	26-Jul-21	P
Chevron	039-895-629	758	759	M	A	17-Jun-20	1	25-May-22	P

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
Stripe Dot	040-011-028	764	765	F	A	18-Jun-20	1	02-Jul-21	C
Diamond	039-782-318	783	785	F	A	25-Jun-20	1	13-Jul-21	P
H 3 Dots	039-889-585	790	791	F	A	27-Jun-20	1	25-May-22	P
Divide	039-782-032	792	793	M	A	29-Jun-20	1	21-May-22	P
Arrow	039-635-598	794	795	F	A	29-Jun-20	1	25-May-22	P
M	039-639-378	796	797	M	A	29-Jun-20	1	03-May-21	C
4	039-783-785	326	327	F	A	30-Jun-20	1	08-Jul-21	P
Triangle	040-017-010	328	329	M	A	30-Jun-20	1	30-Apr-21	P
U	040-031-073	330	331	M	A	30-Jun-20	1	18-Jul-21	P
N	N/A	332	333	F	J	03-Jul-20	1	03-Jul-20	C
Circle stripe	040-049-267	334	335	F	J	03-Jul-20	1	25-May-22	P
Bee	N/A	336	337	M	Y	03-Jul-20	1	13-May-21	V
#	039-892-344	340	341	M	J	08-Jul-20	1	17-Jun-21	C
P	039-875-782	338	339	M	A	08-Jul-20	1	25-May-22	P
W	039-890-881	348	349	F	J	11-Jul-20	1	11-Jul-20	C
Smiley Face	039-535-570	350	352	F	Y	11-Jul-20	1	23-May-22	P
F	040-019-862	353	354	M	J	12-Jul-20	1	05-Aug-20	C
Equal not	039-887-047	357	358	M	A	18-Jul-20	1	25-May-22	P

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
2	039-849-256	367	368	M	J	29-Jul-20	1	29-Jul-20	C
1	039-592-344	369	370	M	J	29-Jul-20	1	08-Jun-21	P
Lightning bolt	039-773-518	371	372	F	J	31-Jul-20	1	07-May-22	P
Triangle dot	039-565-846	373	374	F	J	31-Jul-20	1	20-May-22	P
XD	040-029-770	375	376	M	J	05-Aug-20	1	05-Aug-20	C
377/378	N/A	377	378	F	Y	05-Aug-20	1	05-Aug-20	C
Mickey	039-596-573	379	380	M	J	06-Aug-20	1	06-Aug-20	C
Nike	039-624-581	300	301	F	A	23-Apr-21	1	27-Apr-21	C/P
!!	039-601-590	302	303	F	A	27-Apr-21	1	14-Aug-21	C
++	039-793-595	306	307	M	A	28-Apr-21	2	23-May-22	P
conifer	039-881-264	308	309	F	A	28-Apr-21	2	19-Jul-21	P
XX	039-639-834	318	319	F	A	29-Apr-21	1	26-Jul-21	P
Square stripe	039-600-892	310	322	F	A	29-Apr-21	1	07-May-22	C
Line X	039-522-846	316	317	M	A	29-Apr-21	1	29-Apr-21	C
Sunshine		314	315	F	Y	30-Apr-21	2	30-Apr-21	C
Line-dot-line		312	313	M	A	30-Apr-21	2	30-Apr-21	C

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
Upside down cross	039-836-864	385	386	M	A	03-May-21	1	23-May-22	P
Down arrow	040-022-878	390	391	M	A	25-May-21	2	11-Jun-21	P
III	039-887-319	395		F	A	25-May-21	2	07-May-22	C
393/394	Diamond Dot	393	394	F	A	25-May-21	2	30-Jul-21	P
Square Dot	039-850-829	392		M	Y	26-May-21	2	25-May-22	P
Air Sign	040-029-882	222	223	F	A	03-Jun-21	1	23-May-22	P
Bullseye		220	221	F	A	03-Jun-21	1	03-Jun-21	C
Venus	039-852-110	218	219	M	Y	03-Jun-21	1	20-Jul-21	C
+		214	215	M	A	13-Jun-21	3	13-Jun-21	C
212/213		212	213	F	Y	13-Jun-21	3	13-Jun-21	C
Rump	039-771-590	210	211	M	Y	17-Jun-21	1	17-Jun-21	C
Little a	040-000-622			F	J	26-Jun-21	2	26-Jun-21	C
Filled in square	039-887-636	362	209	F	A	26-Jun-21	2	03-Jul-21	C
Little b	039-771-523			M	J	26-Jun-21	2	26-Jun-21	C
X dot	040-007-272				J	02-Jul-21	1	24-Jul-21	P
11	040-046-595			M	J	03-Jul-21	2	21-Jul-21	P

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
12	039-863-618			M	J	03-Jul-21	2	22-Jul-21	P
13	039-638-259			M	J	03-Jul-21	2	25-May-22	P
Little c	039-884-296			M	J	03-Jul-21	2	03-Jul-21	C
41	039-634-374			M	J	03-Jul-21	2	03-Jul-21	C
Point	039-855-259			F	J	04-Jul-21	1	04-Jul-21	C
Squared	039-881-876			F	J	04-Jul-21	1	23-Jul-21	P
Filled in heart	039-580-378			F	J	04-Jul-21	1	04-Jul-21	C
Squiggle dot				M	J	07-Jul-21	3	07-Jul-21	C
Double stripe	041-277-636			F	J	08-Jul-21	2	11-Jul-21	C
7/eleven	041-086-796	207	208	M	A	09-Jul-21	1	23-May-22	P
Triple stripe	041-067-622			M	J	11-Jul-21	2	11-Jul-21	C
Crescent	041-109-000			M	J	11-Jul-21	2	11-Jul-21	P
Triangle line	041-109-886	205	206	F	A	11-Jul-21	2	12-May-22	C
Dot X	041-103-314				J	11-Jul-21	2	25-Jul-21	P
Double wave	041-279-775			F	J	20-Jul-21	1	23-May-22	P
Pep	041-075-623	212	213	M	A/Y	20-Jul-21	1	10-May-22	P

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
!+	041-102-011			M	J	20-Jul-21	1	20-Jul-21	C
Line-circle-line	041-071-025	243	244	M	J	26-Jul-21	1	03-Aug-21	C
Snipe	041-268-358	241	242	M	J	28-Jul-21	1	04-Aug-21	C
IV	041-066-850	235	236		J	04-Aug-21	2	16-Aug-21	P
VI	041-276-806	233	234	M	J	04-Aug-21	2	10-Aug-21	C
Domino	041-069-002	231	232	M	A/Y	04-Aug-21	2	11-Aug-21	P
H E	041-082-884	227	228	F	Y	05-Aug-21	1	05-Aug-21	C
5 dots	041-063-787	226		M	A/Y	05-Aug-21	1	05-Aug-21	C
PE	041-103-355	274	275	M	J	11-Aug-21	2	11-Aug-21	C
$	041-270-590	251	252	M	A	6-May-22	2	6-May-22	C
Sad face	041-061-280	254	255	M	A	7-May-22	1	7-May-22	C
Tri-dot	041-062-811	256	257	M	Y	7-May-22	1	7-May-22	C
N/A	N/A	269		F	A	7-May-22	1	7-May-22	C
N/A	040-009-114	267	268	F	A	7-May-22	1	7-May-22	C
Eye	041-114-281	265	266	M	A	12-May-22	2	12-May-22	C
N/A	041-075-059		264	F	Y	12-May-22	2	12-May-22	C
Angry face	041-076-887	262	263	M	A	12-May-22	2	12-May-22	C

Dye Mark	PIT	Ear Tag		Sex	Age	First capture	Capture Location	Last detection	Method
Sunny	041-088-537	260	261	F	A	12-May-22	2	12-May-22	C
14	041-265-570	258	259	M	Y	12-May-22	2	12-May-22	C
IVI	041-294-073	276	277	F	Y	16-May-22	2	16-May-22	C
Double chevron	040-031-627			M	A	04-Apr-21	1	26-May-22	P
Dot cross	041-274-812	201	202	M	Y	20-Jul-21	1	23-May-22	P

Table 2. Survival Squirrel ID, sex, age, translocation period, date of last detection and presumed fate at the end of the field season for Columbian ground squirrels translocated in 2020 and 2021 from Site 1and Site 3 (denoted with *) to Site 2.

Squirrel ID	Sex	Age	Translocation Period	Last Detection	Fate
I	Female	Adult	July 2020	April 2021	Disappeared[1]
Infinity	Male	Juvenile	July 2020	June 2021	Disappeared
Y	Male	Juvenile	July 2020	August 2020	Disappeared
heart	Female	Juvenile	July 2020	August 2020	Disappeared
star	Female	Juvenile	July 2020	August 2020	Disappeared
Vertical 2 dots	Female	Adult	July 2020	July 2020	Disappeared
=	Female	Juvenile	July 2020	August 2020	Disappeared
one dot	Female	Juvenile	July 2020	August 2020	Disappeared
S	Male	Juvenile	July 2020	June 2021	Disappeared
H	Male	Juvenile	July 2020	June 2021	Disappeared
O	Male	Adult	July 2020	August 2020	Disappeared
X	Male	Adult	July 2020	August 2020	Disappeared
Horizontal 2 dots	Female	Adult	July 2020	July 2020	Disappeared
Dash	Male	Adult	July 2020	May 2021	Disappeared
Tripod	Male	Adult	July 2020	July 2020	Disappeared
A	Female	Adult (pregnant)	May 2021	May 2022	Alive

Shoulders	Female	Yearling	May 2021	June 2021	Disappeared[1]
Squirrel ID	**Sex**	**Age**	**Translocation**	**Squirrel ID**	**Sex**
Z	Female	Yearling	May 2021	June 2021	Deceased[2]
V	Male	Adult	May 2021	July 2021	Deceased[2]
Stripe	Female	Adult (pregnant)	May 2021	August 2021	Disappeared
3 dots	Female	Yearling	May 2021	May 2021	Disappeared
Squig*	Female	Adult	May 2021	May 2022	Alive
little squiggle*	Female	Juvenile	July 2021	August 2021	Disappeared
wave*	Male	Juvenile	July 2021	August 2021	Disappeared
NN	Male	Adult	July 2021	May 2022	Disappeared
3	Female	Yearling	July 2021	July 2021	Unknown[3]
trident	Female	Yearling	July 2021	August 2021	Disappeared
RC	Female	Adult	July 2021	May 2022	Alive
FHC	Female	Juvenile	July 2021	May 2022	Alive
HCL	Male	Juvenile	July 2021	August 2021	Disappeared
HC	Female	Juvenile	July 2021	July 2021	Disappeared

[1] Collar found near or on release site.

[2] Coyote predation

[3]Apparently shed collar and escaped from enclosure.

Appendix D

Habitat selection by Columbian ground squirrels.[1]

Ellen A Smith[1], Brianna M Lorentz[1], Emily M Holden[1], Colleen C St. Clair[1]

[1]Department of Biological Sciences, University of Alberta, Edmonton, Alberta, Canada

[1] This research was completed as a fourth year undergraduate research project by Ellen Smith. Minor changes were completed in January 2023 by Brianna Lorentz. The abstract for this work has been removed to fit thesis submission requirements but can be found in the original work.

Introduction

Human pressures on the natural environment already exceed 75% of the land area (Venter et al. 2016) and are accelerating in many locations (European Commission, 2006; Steffen et al. 2015). Anthropogenic disruption of natural habitat affects wildlife species in numerous ways, including changes in the behaviour of individuals (Shannon et al. 2014; Ellington and Ghert 2019; Keller et al. 2021) population density and distribution (Benítez-López et al. 2010), altered predator-prey relationships (ref), and changes to community composition (ref). These changes often identify a gradient of species responses that range from avoidance of humans and their infrastructure to adaptation and even exploitation (sensu Blair 1997, McKinney 2002). Some species that contribute beneficially to the function of natural ecosystems in some contexts, generate conflict with people if they successfully adapt to and exploit urban areas (e.g., ref, ref).

Human-wildlife conflicts are defined as interactions between wildlife humans with a negative outcome (Madden 2004), but they typically connote inconvenience or threats to people (Conover 2002). Such conflict involves many rodent species that are designated as pests, because they frustrate homeowners and land managers with negative effects on agriculture yield and aesthetic vegetation (Delibes-Mateos et al. 2011; Davidson et al. 2012). For example, white-footed mice (*Peromyscus leucopus*), which occur in large populations in urban predator-refugia areas created by humans (Sorace 2002; Møller 2012; Shannon 2014; Kelleher 2021). Burrowing rodents create additional disturbance to lawns, sidewalks, and buildings. In addition to effects on anthropogenic land cover, prey species may create conflict by attracting predators to urban areas (McCabe et al. 2018). For example, synanthropic rodents support populations of urban coyotes (*Canis latrans*), which are often found in greater numbers in urban areas than in natural habitats

(Sorace 2002; Bateman & Fleming 2012). Large numbers of predators near people open opportunities for conflict from disease and animal attacks (Murray et al. 2016; Bateman & Fleming 2012). Columbian ground squirrels (*Urocitellus columbianus*; hereafter 'ground squirrels') are semi-fossorial mammals that occur throughout the Rocky Mountains (Boag & Murie 1981; US ref). Like other ground-dwelling, burrowing rodents, they are important ecosystem engineers, distributing nutrients in soil and acting as prey for other animals (Delibes-Mateo 2011; Davidson et al. 2012). Natural predators of CGS include grizzly bears (*Ursus arctos*), coyotes, and mountain lions (*Puma concolor*) (Reviewed by Elliot and Flinders 1991). Ground squirrels are frequently drawn to agricultural contexts and human infrastructure owing to food resources (e.g., ref) and human shields as protection from predators (e.g., ref). In these contexts, the burrowing activities of ground squirrels are frustrating for land managers since burrows are perceived as interfering with the maintenance of developed landscapes (Alberta Agriculture and Rural Development 2006; Delibes-Mateo 2011; Davidson et al. 2012). CGS have previously been managed through lethal means (Albert and Record 1981), but this strategy also removes beneficial ecosystem services and is increasingly distasteful to members of the public. However, there is a lack of knowledge surrounding the efficacy of many non-lethal management methods. For example, the planting of tall vegetation by Fitzgerald & Marsh (1986) was expected to reduce CGS success but proved expensive and ineffective. This void of conservation procedures means that other avenues of management must be explored.

One possible mitigation of potential CGS-human conflict is to translocate squirrels to locations without adjacent human development. This proposed action has been supported by wildlife managers in Jasper National Park. However, for translocation to be successful, CGS must be moved to new locations with suitable habitat conditions (Roe & Roe 2003). Weddel

(1989) described open areas with dense vegetation and the presence of native forbs as important habitat features for CGS. However, there is a lack of consistent and statistically rigorous descriptions of CGS habitats in the Canadian Rockies. Therefore, the aim of this study was to characterize and predict habitat selection by CGS.

Methods

Study site

The study was conducted in and around the townsite of Jasper, AB, Canada (52.8737° N, 118.0814° W). These sites are classified as montane ecoregions (Environment Canada & Agriculture Canada 1983), characterized by mixed grasslands and Douglas fir stands (Parks Canada 2017). All sites were in relatively natural areas but occurred near roads or other human infrastructure.

Study design

We sampled eight sites consisting of local-scale paired zones, one squirrel occupied zone and one squirrel unoccupied zone. Occupied zones had active squirrel populations, as determined by visual presence of squirrels or recent burrowing activity. Unoccupied zones were within 40 - 150 m of each occupied site and appeared to have suitable habitats upon coarse visual inspection, but contained no visible squirrels or burrows with recent burrowing activity. Sampling sites were selected to maintain as much similarity between paired sites as possible while avoiding influences on the vegetation of unoccupied areas due to squirrel foraging. Each pair of sites appeared to have similar vegetative, topographical, and land use characteristics. We chose 40m as a buffer between paired sites because nesting female home ranges have been estimated as approximately 30m in diameter (Elliot & Flinders 1991).

In the occupied sites, we located active burrows by visually identifying squirrels in the burrows or the presence of recent digging activity in the form of newly unearthed soil. We took the coordinates of the most central active burrow (the "centroid"). We then laid three parallel 20m transects running N - S with 10m spacing between transects. The central transect was placed with the centroid burrow falling at its midpoint.

We sampled vegetation in eight 50x50cm quadrats, equally spaced with three quadrats per transect, excluding the centroid location as it fell directly over an active burrow. If a quadrat fell over a rock, road, burrow, or other obstructions we moved the quadrat only as far as was necessary to exclude the obstruction. Vegetative community composition was then determined by visually estimating the percent cover for all identifiable species or genera in each quadrat. Some plants could not be identified to species, and so we grouped them by genus, including all *Poa*, *Carex*, *Astragalus*, *Antennaria*, and *Elymus* species. To sample average vegetative height, we place a 50cm transect running N-S directly through the center of each quadrat, measuring the height of six plants at 0, 10cm, 20, 30, 40, and 50cm marks. If no plant was directly at the cm mark, the nearest plant was measured.

Rough measures of soil texture and moisture in each quadrat were then taken. To measure soil moisture, we used a step core to retrieve soil samples at least 48 hours after a precipitation event. Samples were placed in paper coin envelopes then dried at 38°C for at least 48 hours. We calculated percent soil moisture as the weight of dry soil divided by the weight difference between wet and dried samples. To measure soil texture, we used a step core to take one sample from each quadrat. All soil cores for each site were pooled. Soil texture was then determined following the procedure for hand texturing in a soil texture key (British Columbia Ministries of Environment, and of Forests and Range 2010).

To sample the paired unoccupied site, we moved at least 40m away from the occupied zone and randomly chose a centroid location. We repeated the same protocol at the unoccupied site. However, we sampled nine quadrats instead of eight, as the lack of active burrows allowed us to place a quadrat at the centroid. We sampled a total of 153 plots across all sites and zones.

To measure spatial variables, we used ArcMap v.10.7.1. To determine the distance from each centroid to the nearest road, we used the "near" tool and a raster of roads (Parks Canada 2022) in and around the Jasper townsite. To determine the distance to the nearest tree cover, distance to the nearest railway line, and distance to the nearest high traffic human use area, we estimated using the distance tool and recent satellite imagery (Esri 2009).

Statistical analysis

We used principal component analysis (PCA) and non-metric multidimensional scaling (NMDS) ordinations to visualize plant communities using packages vegan and ggvegan in program R v.1.2.5042 (Oksanen et al., 2017; Simpson, 2019, R Development Team YEAR). One occupied site on a hill (52.8936° N, 118.0679° W) was identified as an outlier in the NMDS output and was subsequently excluded from all vegetative community analyses. We extracted PCA axis loadings of principal components one and two to use as covariates in a resource selection function, with which we compared several other environmental variables.

To test if any of our measured variables were related to the probability of CGS occurrence, we used mixed-effects logistic regression models. Models implemented a used/unused resource selection function design, comparing resource covariates at occupied and unoccupied zones. We used univariate logistic regression models using the lmtest and car packages (Zeilies and Hothorn, 2002; Fox and Weisberg, 2019). As independent variables, we measured the distance from the site centroid to each of the nearest road, tree cover, railway line, high traffic human use area, as well as average vegetative height, axis loadings of principal components one and two, % soil moisture, soil stickiness, and soil graininess. We retained the variables that were significant at $P < 0.25$, eliminated correlated variables, and then constructed a GLM using all remaining variables to create a resource selection function using logistic regression. We compared the whole model to the null model by comparing Akaike information criterion (AIC) weights using package AICcmodavg (Mazerolle, 2020). None of the variables used in our model showed colinearity, suggested by Shafer et al. (2012) as an r value greater than 0.7.

To test for differences in plant community between occupied and unoccupied areas, we ran a permutational multivariate analysis of variance (PERMANOVA), using site types (occupied vs. unoccupied) as blocks. For this, we used the vegan and RVAideMemoire packages (Oksanen et al., 2017; Hervé, 2021).

To determine if soil moisture was helpful in explaining differences in plant communities, we used canonical-correlation analysis (CCA), using packages vegan and ggvegan.
We also conducted an indicator species analysis using the indicspecies package (De Caceres and Legendre, 2009) to identify plant species characteristic of the different site types.

Results

Soil Texture

Occupied zones had mostly slightly grainy soil (20-50% sand), and unoccupied areas had mostly grainy soil (50-80% sand) (Figure 1). Both occupied and unoccupied zones had mostly slightly sticky soil (10-25% clay) (Figure 1). Overall, occupied zones had mainly loamy soils, whereas unoccupied areas were commonly sandy loam (BC Ministries of Environment and of Forests and Range, 2010).

PCA and NMDS

In the PCA, we observed a large degree of overlap between the occupied and unoccupied sites (Figure 2). This indicated that occupied and unoccupied sites are compositionally similar. However, NMDS showed a slight separation of ellipses for occupied and unoccupied sites (Figure 3; Table 1), indicating a difference in vegetative community composition between zones. The first NMDS axis appears to reflect a common/rare species continuum. Common species such as *Poa pratensis subsp. angustifolia* and *Bromus inermis* (both introduced species; Desmet & Brouilet, 2013) fall on the right side of the ordination, while relatively infrequent or rare species such as *Calamagrostis montanensis*, *Erigeron* spp, *Astragalus agrestis*, and *Antennaria* spp. fall on the left side. The second NMDS axis may represent a disturbance continuum, with weedy, rapid colonizers such as *Crepis tectorum* and *Agropyron cristatum subsp. pectinatum* (both introduced species; Desmet & Brouilet, 2013) represented in the lower portion of the ordination space and slower-growing perennial species such as *Anemone multifida*, *Elymus* spp, and *Solidago multiradiata* found in the upper portion of the graph.

RSF

None of the univariate logistic regression models were useful in predicting squirrel occupation. Distances to each of the nearest road, tree cover, railway line, and high traffic human use area were similar along with average vegetative height, axis loadings of principal components 1 and 2, and percent soil moisture, soil stickiness, and soil graininess (Figure 4; Figure 5; Table 2). Soil stickiness and soil graininess results are presented in figure 5. Only the results from the non-grainy (Z=0.000, p=1.000), slightly-grainy (Z=1.337, p=0.181), and sticky (Z=0.630, p=0.529) factor levels are reported, as the R program assigned the “slightly sticky” and “grainy” levels were assigned as references. PC2 was the closest covariate to having significantly scaled log odds of squirrel presence (Z=-1.008, p=0.313).

No resource selection function constructed from any combination of the above variables was useful in predicting squirrel presence, as the AIC weights for all models were higher than that of the null model (null model AIC = 24.181). The model closest to significance was the univariate model of the PC2 axis loading (AIC weight of 25.09).

PERMANOVA

PERMANOVA analysis indicated that there was a significant difference between vegetative communities of occupied and unoccupied zones (F= 2.6126, p= 0.012; Table 3); we observed this result with or without including the outlier, occupied hill site.

Vegetative height, soil, and CCA

Vegetative height and % soil moisture were not significantly different between the occupied and unoccupied zones (Figure 6; Figure 7). The average vegetative height in occupied zones was 17.7 cm (±SE 0.5), and the average height in the unoccupied zones was 17.3 cm (±SE 0.5). The average % soil moisture in occupied zones was 0.402 (±SE 0.017), and the average % soil moisture in the unoccupied zones was 0.387 (±SE 0.018). Additionally, CCA ordination showed that % soil moisture was not useful in explaining variance in our vegetative communities. Therefore, the environmental variables measured were not useful in explaining the difference between occupied and unoccupied zones.

Indicator Species

Significant indicator species (p <0.05) for occupied zones were Festuca *idahoensis*, *Agropyron cristatum subsp. pectinatum*, *Pascopyrum smithii*, *Festuca saximontana* (all grasses), and *Juniperus communis* (a shrub) (Table 4). The significant indicator species for unoccupied zones was *Erigeron* spp (fleabane) (Table 5). *Agropyron cristatum subsp. pectinatum* (crested wheatgrass) and *Pascopyrum smithii* (western wheatgrass) were the only introduced indicator species (Desmet & Brouilet, 2013)

Discussion

In order to aid CGS conservation efforts and conflict mitigation, we attempted to support translocation attempts by characterizing CGS habitat. We found a slight but significant difference in vegetative community composition between occupied and unoccupied zones. However, we were unable to construct a resource selection function that significantly predicted squirrel occupation based on the covariates we measured. Overall, our results may be helpful in pointing to other variables that could be useful in predicting CGS occupation.

Vegetative Community

The average height in occupied areas (17.7cm) was higher than the preferred vegetative height of Columbian ground squirrels previously reported in the literature (between 7.5 and 15cm; Hennessy et al. 2016*)*. However, average vegetative height was not predictive of squirrel presence. Vegetative height is likely not as important for CGS habitat selection as other site characteristics. In the occupied zones, we observed trails in the vegetation between burrows where the vegetation had been flattened by regular CGS movement. Columbian ground squirrels may be able to compensate for increased vegetative height by flattening vegetation along trails to increase their ability to see in their surrounding area (E. Smith, personal observation).

The PERMANOVA indicated community composition differed significantly between the occupied and unoccupied zones. However, plant community descriptors were not able to explain squirrel presence, as evidenced by the higher AIC weights in RSF models including plant community PCA covariates. The significant difference between community types potentially indicates an unmeasured variable related to vegetation could be important to CGS habitat selection. We examined candidate variables that could be driving this difference, including soil moisture and average vegetative height, but found they were not different between zone types. This is further supported by our CCA ordination, which showed that soil moisture was not useful in explaining variance in our vegetative communities.

Interestingly, one indicator species of occupied areas was common juniper (*Juniperus communis*). During our study we observed many burrows under or around juniper bushes, thus the cover provided by shrubs like juniper may be useful for CGS.

The NMDS ordination showed that the ellipses for the distribution of occupied and unoccupied zones were distinct (Figure 3). This appeared to be driven by a split between weedy and perennial native plants along the vertical axis. The occupied ellipse was spread further along this second axis, suggesting occupied zones contained both more slow-growing native species and more disturbance-loving weedy species than unoccupied zones. The horizontal axis appears to represent a rare to common gradient, with the ubiquitous introduced grasses *Poa pratensis* and *Bromus inermis* appearing spatially distinct on the right side of the graph (Figure 3).

The weedy-perennial species separation likely reflects different environmental conditions between occupied and unoccupied zones. Local-scale environmental conditions influence vegetative community composition and traits through habitat filtering (Keddy 1992; Diaz et al. 1998; Cingolani et al. 2007; Bruelheide 2018). Weedy species are likely to have traits on the "fast" side of the life history trait continuum (Reich et al., 2014, Kuester et al. 2014, Sutherland 2004), with characteristics that allow quick resource acquisition and reproduction. Species with these traits are successful in post-disturbance conditions, as they are able to quickly exploit resources when disturbance creates open areas (McIntyre et al. 1995; Smith et al. 2022; Garnier et al. 2004). Therefore, the separation of weedy-perennial species may reflect occupied zones being more likely to occur in disturbed areas, meaning disturbed areas may be favoured by Columbian ground squirrels. One source of disturbance is anthropogenic development. Globally, natural habitats have rapidly reduced as human populations and pressures grow (Venter et al. 2016). In Alberta, the area of land disturbed by human footprint activities have increased, with forestry, agricultural development, and mining especially impactful to the Rocky Mountains (Schieck et al. 2014). As human activities continue to affect natural areas, it will be important to understand the relationship of disturbance to CGS habitat.

One feature of disturbed areas important for habitat selection could be soil type. Columbian ground squirrels are semi-fossorial mammals, with soil playing an important role in their survival (U.S. Fish and Wildlife Service, 2018; Kinlaw 1999). CGS may be more successful in areas with certain characteristics. CGS have previously been observed to burrow in loam without excessive sand (Weddel 1989; Lohr et al. 2013). This was supported by our study, as loam was the most prevalent soil type in occupied zones and sandy loam the most prevalent in unoccupied zones. This difference shows soil characteristics are likely related to habitat selection. Plant community differences could be driven by unmeasured soil characteristics, as soil features including pH and nutrient content are related to vegetative community characteristics (Song et al. 2019; Dale et al.1992; Dodd et al. 2002). The relationship between soil and plant communities could explain why the vegetative community did not predict presence, even when a significant difference between the communities of occupied and unoccupied zones was detected. However, we found that neither soil texture nor moisture were significantly useful for predicting squirrel occupation. Thus, more thoroughly examining a larger suite of soil characteristics could be useful in explaining habitat selection.

Resource Selection Function

No resource selection function constructed from our covariates was more parsimonious than the null model. Additionally, when examined individually, none of our covariates significantly predicted squirrel occupation.

Future Directions

Because our site comparison occurred at a local scale (sites within 150M of each other), it may have been difficult to detect differences in our variables with this sample size. When examining differences at this scale, more extensive detailing of sites may be required. We suggest emphasizing finer-scale, specific features of occupied areas such as total aboveground biomass. We found that juniper was a significant indicator species of occupied zones, possibly due to the protective cover bushes provide. Therefore, we suggest investigating other habitat characteristics such as the presence of tree stumps and rocks which could provide cover for burrows.

Although vegetative communities were significantly different between occupied and unoccupied zones, synthetic vegetation variables from the PCA were not useful in predicting squirrel presence. This difference may be reflecting a more important difference in soil conditions at different sites, as plant communities are related to soil type. Future studies should investigate bulk density and organic matter content of the soil in occupied areas, as these are useful and easily determined soil characteristics (Chaudhari et al. 2013; Saini 1966; Chenu 2015; AL-Shammary et al. 2018). These features remain constant despite moisture content of soil, and so will more reliably quantify soil type in CGS habitats. Additionally, investigating the impact of disturbances may shed more light on habitat selection influences; this can also be investigated through soil analysis. Future researchers should look for evidence of disturbance evidenced by erosion and altered or missing soil horizon layers (Deák et al. 2017; Napper et al. 2009).

One example of a potentially impactful disturbance is the use of fire-smart procedures. During the course of our study, a colony of squirrels (which was not included in our analysis) was observed in an area that had been treated using fire-smart procedures (E. Smith, personal observation). In order to reduce the risk of fire quickly spreading, areas treated by fire-smart protocols have large amounts of trees removed (Parks Canada 2021; Parks Canada 2022). This impacts the vegetative communities by reducing shading on shorter plants and also provides new burrow coverage for squirrels via tree stumps. Additionally, ash from controlled burning changes soil nutrient content and pH, stimulating plant growth (Bodí et al. 2014). The success of squirrels in these areas warrants additional investigation.

If soil and disturbance conditions are found to be useful in predicting occupation, the relationship between vegetative communities and these conditions could be extremely helpful in assisting conservation efforts. For example, if indicator species of occupied sites are found to have a correlational relationship to disturbance and soil conditions favoured by CGS, looking for the presence of the indicator species may provide an accessible first step for land managers to identify suitable habitat conditions for translocation.

Conclusions

Overall, we can conclude that the variables investigated in our study were not significant predictors of CGS habitat selection. However, the significant difference between plant communities of occupied and unoccupied zones shows that zones differed in ways that could not be quantified with coarse measures of land coverthis study, potentially in presence of protective cover, soil bulk density, or disturbance level. Future efforts should be focused on fine-scale soil and habitat metrics to better understand CGS habitat selection.

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Appendix D

Tables and Figures

Table 1: Legend and names of significant species (p=0.001) from NMDS plot (Figure 3)

Legend	Name	Common Name
A	*Agropyron cristatum subsp. pectinatum*	Crested wheatgrass
B	*Anemone multifida*	Cut leaf windflower
C	*Antennaria spp*	Pussytoes
D	*Astragalus agrestis*	Purple milkvetch
E	*Bromus inermis*	Smooth brome
F	*Calamagrostis montanensis*	Plains reed grass
G	*Crepis tectorum*	Narrowleaf hawksbeard
H	*Elymus spp*	Quackgrass
I	*Erigeron spp*	Fleabane
J	*Festuca idahoensis*	Blue bunchgrass
K	*Juniperus communis*	Common juniper
L	*Poa pratensis subsp. angustifolia*	Kentucky bluegrass
M	*Solidago multiradiata*	Rocky mountain goldenrod

Table 2: Scaled selection coefficients (β ± SE) of univariate mixed-effects logistic regression models.

	Scaled β (±SE)	Pr (>F)
Distance to road	-0.248 (±0.524)	0.636
Distance to tree cover	-0.327 (±0.551)	0.552
Distance to railway	-9.504e-02 (±5.175e-01)	0.854
Distance to human use area	-0.230 (±0.523)	0.660
PC1 axis	8.254e-02 (±5.177e-01)	0.873
PC2 axis	-0.559 (±0.555)	0.313
Average vegetative height	-2.528e-02 (±5.166e-01)	0.961
% soil moisture	0.328 (±0.530)	0.535
Soil stickiness: sticky	0.847(±1.345)	0.529
Soil graininess:	-1.060e-15	1.000

non-grainy	(±1.500e+00)	
Soil graininess: slightly-grainy	1.609e+00 (±1.204e+00)	0.181

Table 3: Results of the PERMANOVA of vegetative communities from occupied and unoccupied zones.

	Df	Sum Of Squares	R^2	F	Pr (>F)
Occupied	1	0.809	0.020	2.613	0.005
Residual	126	39.010	0.980		
Total	127	39.818	1		

Table 4: Significant indicator species of occupied zones.

Species	p value
Festuca idahoensis	0.020
Agropyron cristatum subsp. pectinatum	0.002
Pascopyrum smithii	0.004
Festuca saximontana	0.010
Juniperus communis	0.011

Table 5: Significant indicator species of occupied zones.

Species	p value
Erigeron spp	0.010

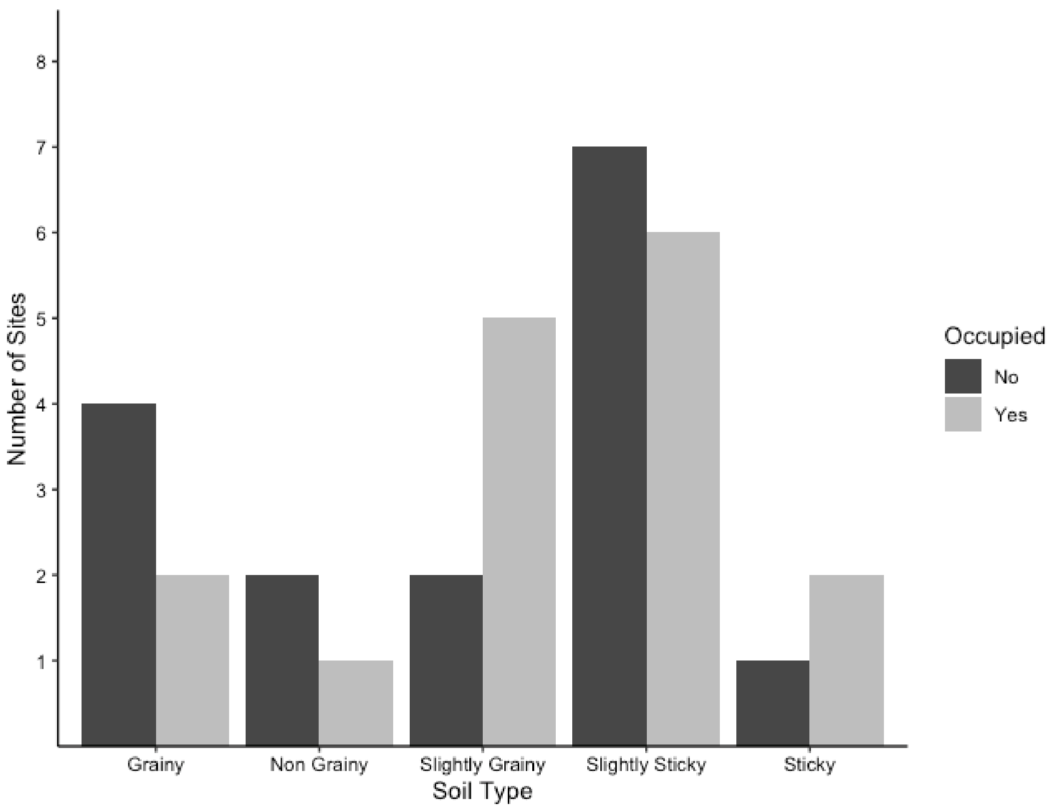


Figure 1: Soil texture in occupied and unoccupied zones. Occupied zones had mostly loam, and unoccupied areas had mostly sandy loam (BC Ministries of Environment and of Forests and

Range, 2010).

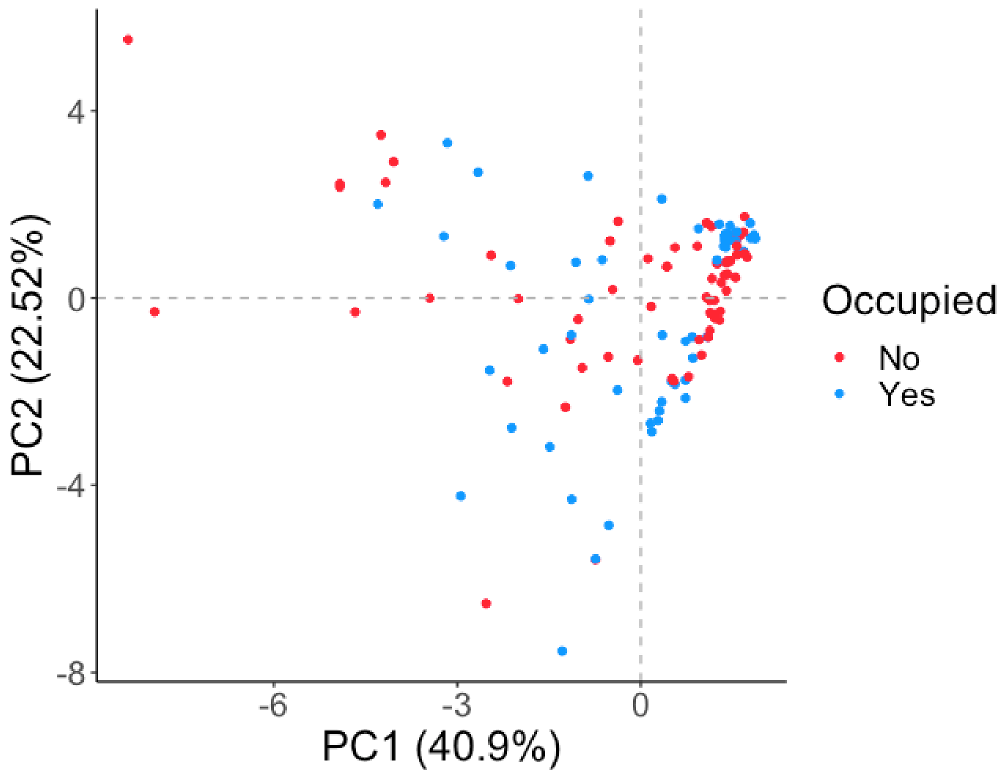


Figure 2: PCA ordination of vegetative species abundance data from unoccupied and occupied areas. A large degree of overlap of occupied and unoccupied areas was detected.

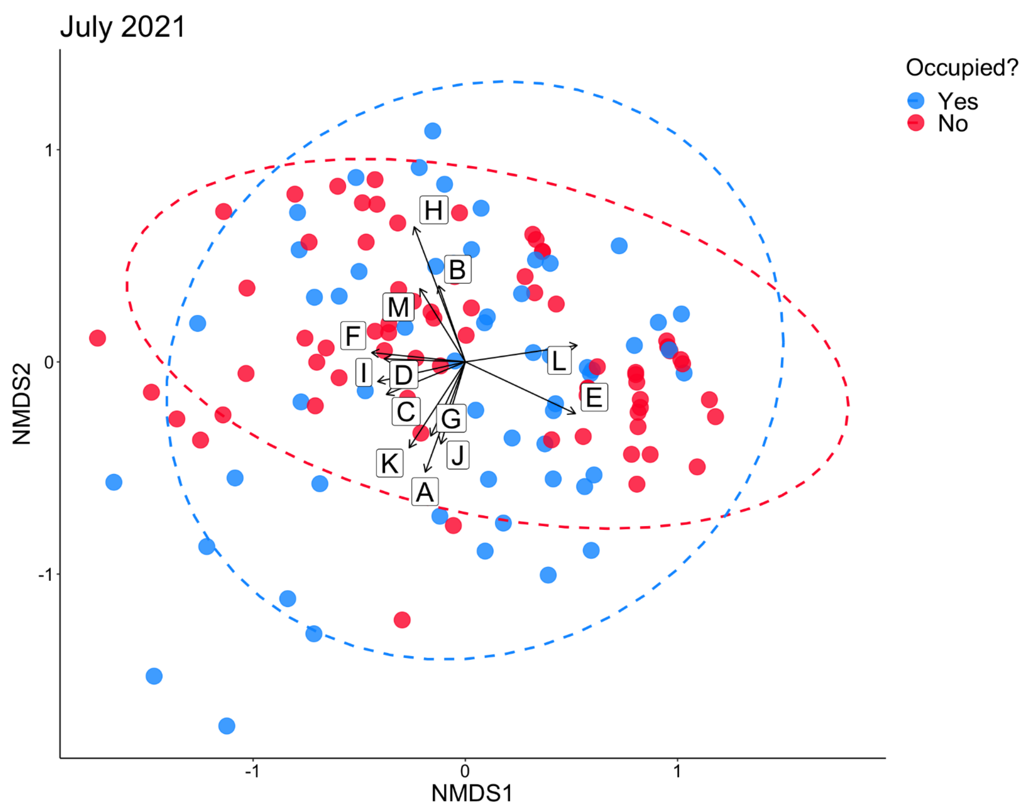


Figure 3: NMDS ordination of vegetative species abundance data from unoccupied and occupied areas. The species associated with the upper area of the distribution are *Anemone multifida* (B), *Elymus spp* (H), *Solidago multiradiata* (M). Those associated with the bottom are *Juniperus communis* (K), *Crepis tectorum* (G), *Agropyron cristatum subsp. pectinatum* (A), and *Festuca idahoensis* (J). The species associated with the right side of the distribution are *Poa pratensis subsp. angustifolia* (L) and *Bromus inermis* (E). Those associated with the left side are *Calamagrostis montanensis* (F)*, Erigeron* spp *(I), Astragalus agrestis* (D)*, Antennaria* spp (C). Associated species had a p equal to or less than 0.001.

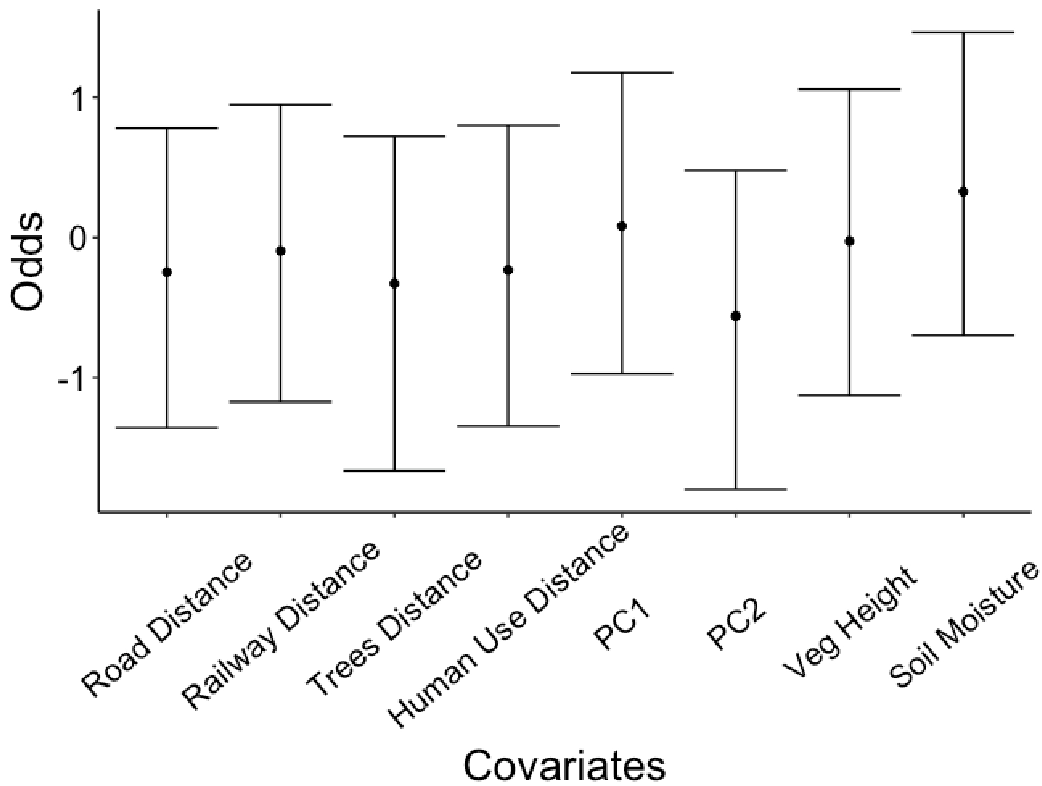


Figure 4: Univariate mixed-effects logistic regression models of habitat selection by Columbian ground squirrels with scaled log odds. Error bars represent 95% confidence intervals. All confidence intervals overlapped zero, indicating Columbian ground squirrels did not display significant selection or avoidance of any covariate.

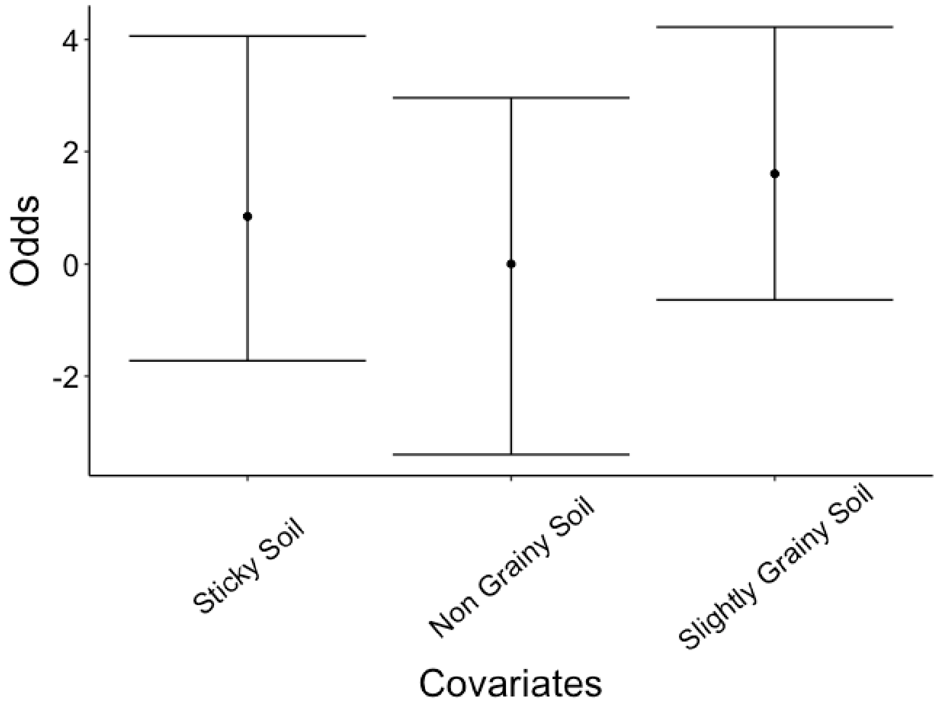


Figure 5: The log odds of squirrel presence from soil texture. Error bars represent 95% CI's. Confidence intervals of all soil texture covariates overlapped zero, indicating Columbian ground squirrels did not display significant selection or avoidance of these texture covariates.

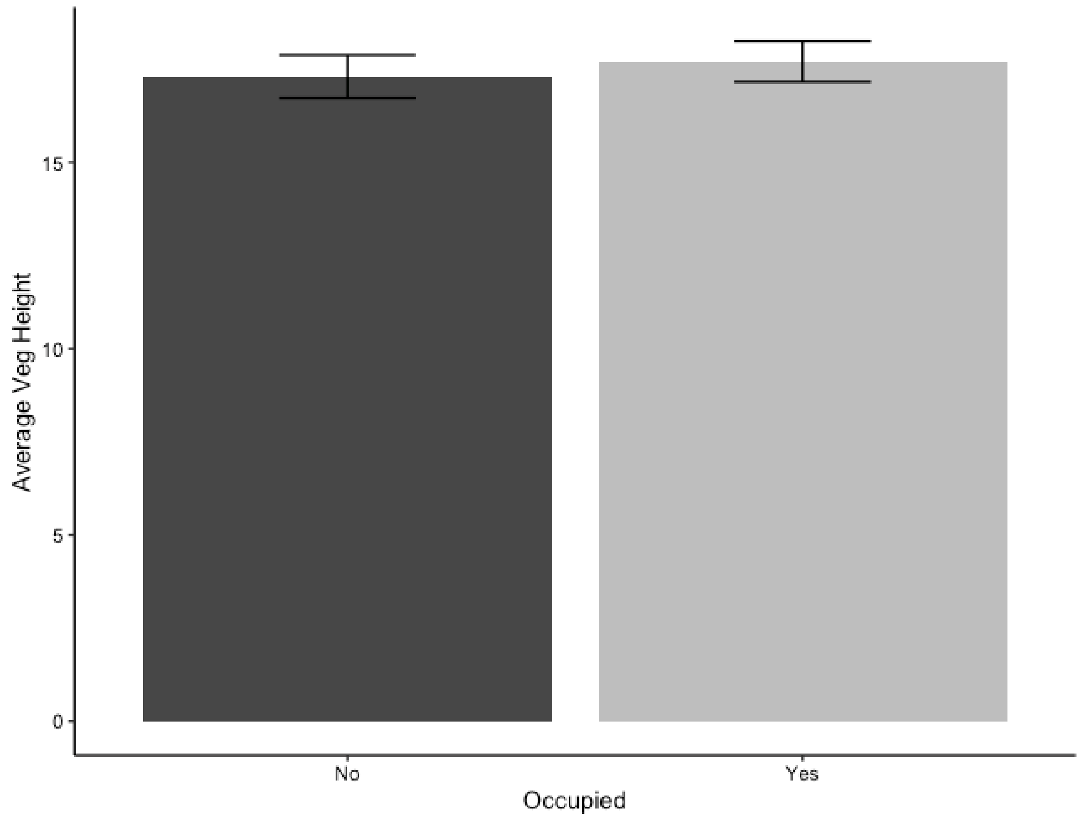


Figure 6: Average vegetative height in occupied and unoccupied zones. Error bars represent standard error. The average vegetative height in occupied zones was 17.7 cm (±SE 0.5), and the average height in the unoccupied zones was 17.3 cm (±SE 0.6). The average height was not significantly different between zone types.

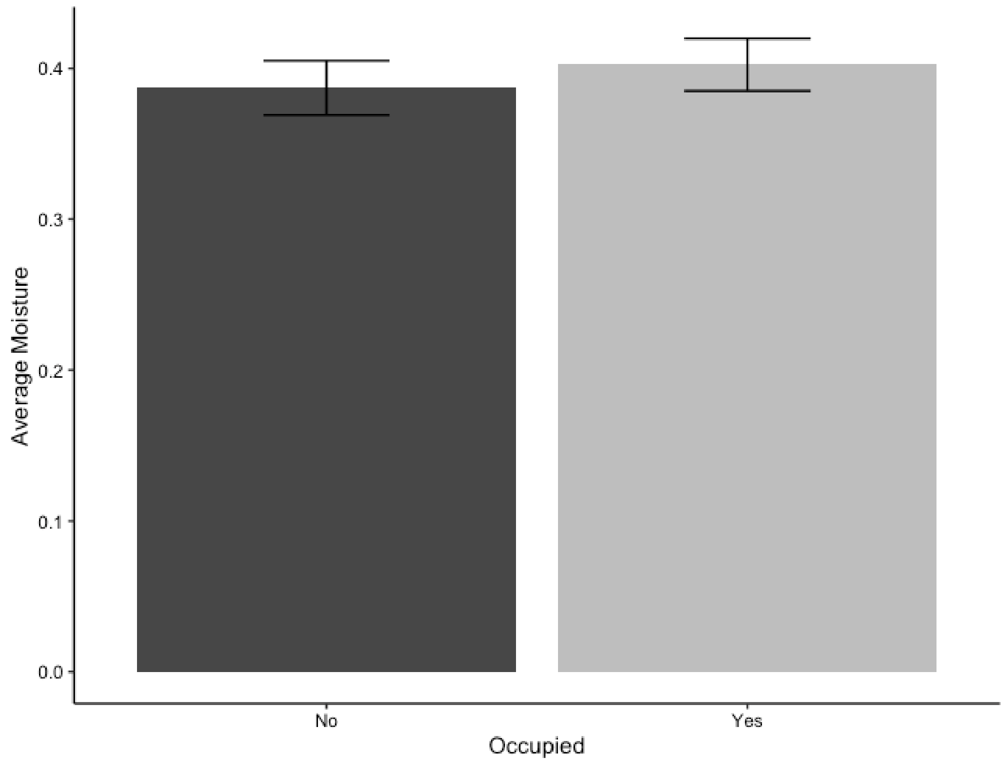
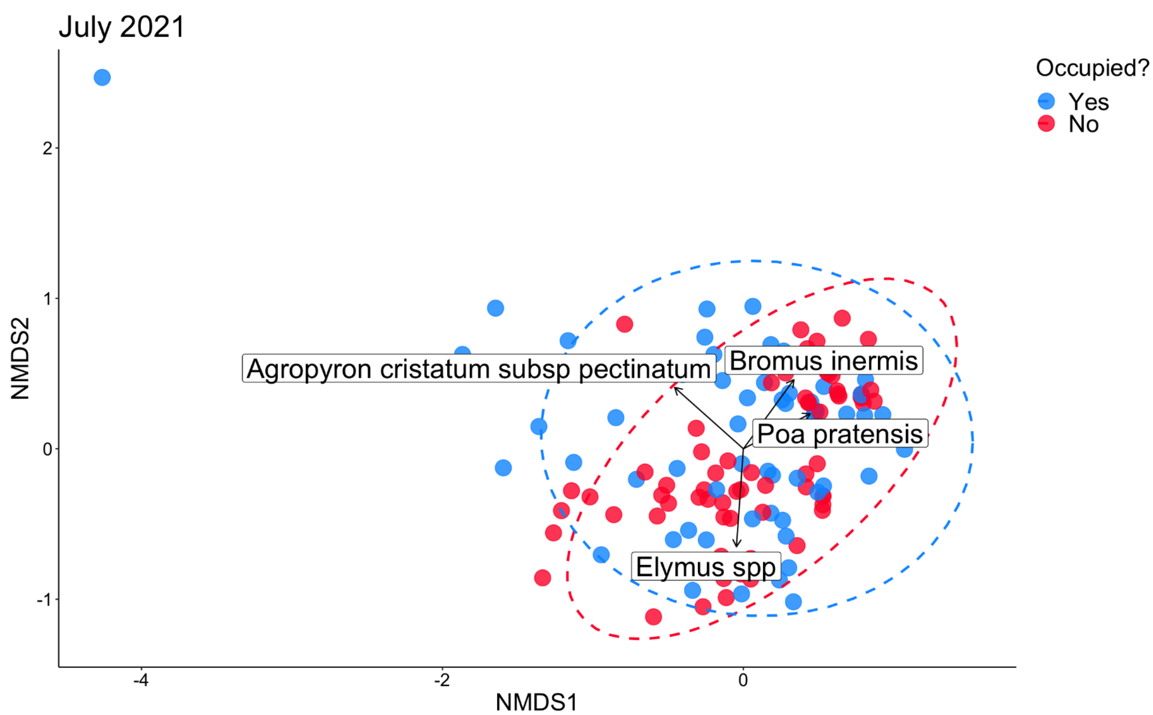


Figure 7: Average % soil moisture in occupied and unoccupied zones. Error bars represent standard error. The average % soil moisture in occupied zones was 0.402 (±SE 0.017), and the average % soil moisture in the unoccupied zones was 0.387 (±SE 0.018). % soil moisture was not significantly different between zone types.



Supplementary Figure 1: NMDS ordination of vegetative species abundance data from unoccupied and occupied areas, including outlier community. The outlier community, visible in the top left, was the occupied zone of the "hill" site. Associated species had a p equal to or less than 0.001.