

## Small Mammal Use at a Military Installation and Implications for Bird Strike Risk

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**Abstract** - Bird strikes with aircraft are a major safety issue. On military installations collision risk not only has safety implications but also poses a concern for national security. As a result, evaluations of bird attractants at airfields and surrounding landscapes are conducted to better understand and mitigate these collisions. Grand Forks Air Force Base (GFAFB) is a 2336-ha installation within a complex surrounding landscape, including state and federal wildlife conservation areas. Raptors pose a high hazard potential due to their large size and soaring behavior, so we evaluated their food availability at GFAFB by conducting a small mammal inventory in 2021 and 2022. Sherman live traps were placed every 5 m along eighteen 125-m transects on-base ( $n = 9$ ; 3 on-airfield and 6 off-airfield) and off-base ( $n = 9$ ) to evaluate the management objective that the base is at least no more attractive than the surrounding off-base sites. Traps were checked in the morning and evening for 3 consecutive days each season (spring, summer, and fall). Additionally, we sampled the vegetation structure, litter depth, and dominant plant composition to understand the habitat characteristics of seasonal small mammal abundance and distribution. We detected 11 species groups in 374 captures on-base and 248 captures off-base. We found no statistical difference in catch per unit effort among the 3 vegetation treatments surveyed: on-base-airfield, on-base-off-airfield, and off-base. We demonstrate within our study site that small mammal occurrence and vegetation height peak in the fall, suggesting there is a seasonal effect on raptor food availability at GFAFB. Further, we found a positive correlation between vegetation structure and small mammal capture rate independently of the season. We found  $\leq 66\%$  dominant vegetation across all sites to be exotic grass/forb and noxious weeds. Our findings suggest that managers should focus on summer to fall for direct management of small mammals and vegetation reduction in structure of all areas on-base if attempting to decrease small mammals therefore decreasing the attractiveness of the base for raptors.

### Introduction

Bird strikes are an issue that the aviation industry has been facing since its beginning. Within the military sector of the field there is a higher vulnerability for aircraft due to the diverse mission sets that can often bring their flight paths lower to the ground than civilian operations (Pfeiffer et al. 2018). During 1985–1998, bird strikes accumulated an average of \$35 million annually in damage for the United States Air Force (USAF; Zakrajsek and Bissonette 2005). Amongst the many guilds of birds that pose issues for bird strikes, raptors are ranked as a high-hazard species group for both civilian and military hazard indices (Dolbeer et al. 2000, Zakrajsek and Bissonette 2005, Pfeiffer et al. 2018). As a result, there is substantial interest in mitigation efforts to reduce raptor presence in and around airfields. Mitigation efforts can take the form of lethal removal, relocation, harassment, habitat management, and prey management. The 2 main groups of harassing tools are auditory deterrents (e.g., gas exploders, alarm and distress calls, and pyrotechnics) and visual repellents (e.g., effigies, predator models, lasers, reflecting materials, lights, mirrors, drones, trained

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dogs and falconry; Metz et al. 2020). Each method has its strengths and weaknesses. For example, harassment often only provides short-term effects, while habitat management creates the most sustainable long-term outcome (Schmidt et al. 2013). Reducing food availability is a key strategy when decreasing raptor presence within a designated area (Witmer and Fantinato 2003). As such, prey removal is another mitigation approach recommended to deter raptor species from airfields. For example, zinc phosphide has been used to lethally reduce the number of small mammals and discourage raptors due to fewer prey resources (Guerrant et al. 2013). Further, studying the spatial and temporal distribution of small mammals can guide management of vegetation structure, composition, and litter depth to discourage small mammals, and in turn, reduce raptor strikes with aircraft (Harris and Davis 1998).

Airfields on military installations are mandated to maintain 17.78–35.56 cm (7–14 inch) vegetation height, commonly achieved through mowing practices for security reasons and to dissuade wildlife from use (BASH GFAFBI91-212 2019). The surrounding areas near airfields on-base can also be managed with practices such as prescribed burns and haying. These practices cause disturbances that small mammals tend to avoid (LaFond et al. 2020). For example, *Microtus pennsylvanicus* Ord (Eastern Meadow Vole) select tall vegetation with litter present. Thus, they are less common in areas of woody encroachment or constant disturbance such as mowing, haying, and prescribed burns (LaFond et al. 2020). In contrast, *Peromyscus* spp., specifically *Peromyscus leucopus* Rafinesque (White-footed Mouse) and *Peromyscus maniculatus* Wagner (Eastern Deer Mouse), are often associated with taller grass, newer growth, and less litter depth (Witmer 2011). These conditions frequently occur after prescribed burn. Thus, if the aftermath of a prescribed burn is left unmanaged, it is more likely to promote *Peromyscus* spp. (Lafond et al. 2020). As a result, if the management goal is to deter the greatest number of small mammals, repeated disturbances are recommended.

Managing vegetation often requires balancing the sometimes-opposing needs of multiple uses or stakeholder objectives, such as conservation and risk management (Blackwell et al. 2013). Military lands fall under the Sikes Act and must maintain the species present using an Integrated Natural Resources Management Plan (INRMP; Omans 1999), while still accomplishing their mission, keeping their personnel safe, and ensuring national security. Further, most bird strikes occur within an 8-km (5-mile) radius when aircraft are at their lowest altitudes for takeoff and landing (DeVault et al. 2017). As a result, managing the surrounding landscape is also crucial for efforts targeted at reducing bird strikes with aircraft. Unfortunately, this is challenging because the surrounding area within the 8-km radius is often not controlled by the airfield. For the most successful outcomes, cooperative management that balances the objectives of stakeholders is vital.

We studied small mammals, vegetation composition, vegetation structure, and litter depth around a military airfield, Grand Forks Air Force Base (GFAFB) in North Dakota, which is situated within a complex landscape of conservation areas and agricultural fields. Specifically, we quantified small mammal occurrences on the airfield, on-base but off the airfield, and off-base at conservation areas surrounding GFAFB within the critical 8-km radius from the airfield. We further evaluated the vegetation structure, dominant cover type, and litter depth across the sites. We aimed to determine whether the habitat on-base, where vegetation can be managed strategically, was of lower or equal attractiveness relative to the surrounding landscape of natural habitat.

## Methods

### Study area

*Grand Forks Air Force Base.* Our study was conducted at GFAFB which is home to the 319<sup>th</sup> Reconnaissance Wing operating the RQ-4 Global Hawk Uncrewed Aerial System (UAS). GFAFB is a 2336-ha (5772-acre) military installation. From January 2010 through December 2019, GFAFB personnel reported 24 wildlife strikes, of which 1 was a raptor (Kuechle 2020). The GFAFB airfield is also used by the Grand Sky UAS business and aviation park. While it is a small installation, it possesses a diversity of habitats, including grasslands along the runway, forested areas scattered throughout, wetlands, and a non-operational golf course on the south side of the fenced property. GFAFB also has man-made sewage lagoons to the east of the main contiguous property, which is largely comprised of open water with turf and rock dams separating the ponds. The lagoons also have trees and shrubs on the north and west sides of the open water. A small portion of the property surrounding the lagoons is grasslands on the westernmost side and a large wetland bordering the lagoon to the north.

GFAFB is surrounded by a complex landscape including conservation land focused on enhancing wildlife and its associated habitats. Within an 8 km radius of GFAFB there is a wildlife management area (Prairie Chicken Wildlife Management Area), 2 waterfowl production areas (Mekinock and Pender Waterfowl Production Areas), U.S. Fish and Wildlife Service National Wildlife Refuge (Kelly's Slough National Wildlife Refuge), Turtle River State Park, University of North Dakota's Oakville Prairie Biological Field Station, as well as private lands entrusted to promote wildlife (e.g., Private Land Open to Sportsmen [PLOTS] and Conservation Reserve Program [CRP; Fig. 1]). Further, Grand Forks Prairie Partners is a collaborative effort among several government, academic, non-governmental, and private entities working towards encouraging high-quality grassland habitat to support wildlife within the county. Their work is centered in GFAFB. Therefore, GFAFB and surrounding landscape are ideal for evaluating the relationships between a variety of vegetation management regimes and small mammal occurrences, which will help with assessing bird strike risk.

*Prairie Chicken Wildlife Management Area.* Prairie Chicken Wildlife Management Area (WMA), managed by the North Dakota Game and Fish Department, has 7 different tracts of land scattered to the north of GFAFB. Our focus was on the 36-ha (89-ac) section of land immediately north of the GFAFB runway. Roughly one-half of this has been leased to agriculture with rotating crops planted annually. In recent years this has included sunflowers, soybeans, and wheat, which often serve as attractants to flocking birds like blackbirds (Icteridae spp.). The other half is comprised of grasslands, small trees, and shrubs with a wetland vein running north and south that attracts grassland birds and several perching raptors.

*Mekinock Waterfowl Production Area.* Mekinock Waterfowl Production Area (WPA) is a 226-ha (558-acre) parcel owned and managed by the U.S. Fish and Wildlife Service (USFWS) and is located to the northeast of GFAFB. Mekinock WPA is comprised of native (untilled) grasslands and scattered wetlands. Mekinock has been managed intensively for the promotion of native prairie. In service of promoting wildlife and maintaining native grasslands in this area, prescribed burning is implemented on a regular basis.

*Pender Waterfowl Production Area.* Pender WPA, also owned and managed by the USFWS, is 350 ha (865 acres) and is immediately east of the GFAFB lagoons. Pender borders other WPA's and is near Kelly's Slough National Wildlife Refuge. Pender is also bordered by private lands, many of which are used for agricultural purposes. During the spring of 2021, prior to the start of our study, a prescribed burn was conducted on the north section. This site has periodic prescribed burns, but these occur at a lower frequency than the Mekinock WPA.

*Oakville Prairie Biological Field Station.* University of North Dakota’s Oakville Prairie Biological Field Station (Oakville), is owned and managed by the university in collaboration with the North Dakota Game and Fish Department as a WMA. This parcel of land is 325 ha (803 ac) of remnant tallgrass prairie located southeast of GFAFB. Oakville is largely comprised of primarily untilled, native prairie with active management occurring in recent years (e.g., prescribed burns). In addition to grasslands and wetlands, there are a few stands of trees and shrubs interspersed throughout.

**Field methods**

*Small mammal.* Fifty-two survey sites were available as part of a larger study examining bird diversity. We randomly selected 18 sites (9 on-base and 9 off-base) to also conduct small mammal surveys. Within the on-base sites we further examined small mammals relative to on-airfield (n = 3) and off-airfield (n = 6) sites. At each small mammal site 25 Sherman.

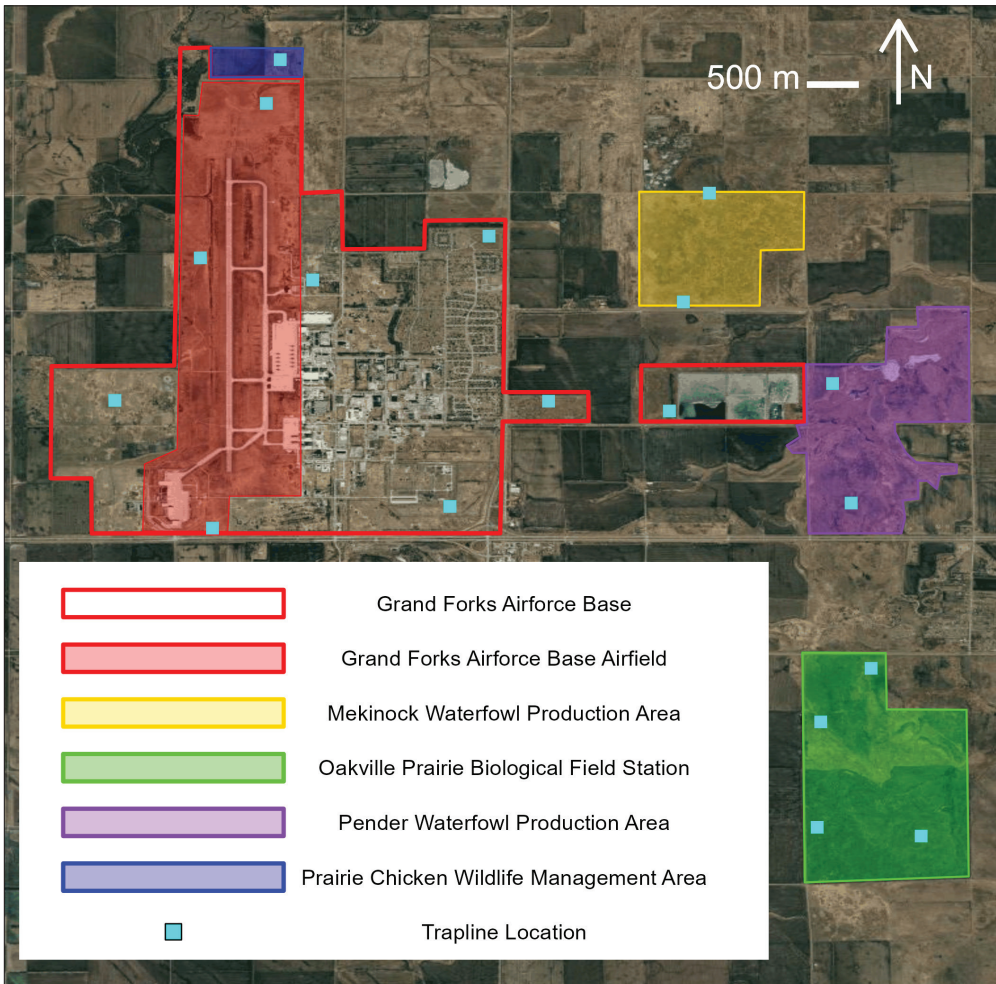


Figure 1. Grand Forks Air Force Base (GFAFB) and surrounding conservation areas surveyed in Grand Forks County, North Dakota (2021–2022) to evaluate small mammal use that may influence attraction of raptors to areas surrounding a military airfield and pose an aviation safety risk.

live traps 7.62 cm × 8.89 cm × 22.86 cm (3 in × 3.5 in × 9 in; H.B. Sherman Traps, Inc., Tallahassee, FL) were baited with peanut butter rolled in oats to determine the number of small mammals captured per trap night. Traps were placed underneath the grass canopy and spaced 5m apart across a 125-m transect (Mills et al. 1995). Each trap line started at the center of each randomly selected site and was oriented east or west from the starting point (Fig. 2). Traps were set for 3 consecutive nights during the spring (2021), summer (2021, 2022), and fall (2021, 2022) survey periods (Fig. 3). Traps were checked twice daily, once in the morning (AM) and in the later afternoon to early evening (PM) to ensure the least amount of stress on the animals. Due to logistics associated with site access, especially on the airfield, we could not check the traps at sunrise and sunset that would have enabled more rigorous evaluations of diurnal and nocturnal movements of small mammals. For each trapline we recorded the latitude and longitude of the position of the first and last traps, the date set, the date checked, the time of check (AM or PM), the sky condition, and the moon phase before checking the trap transect. When checking traps, each trap was recorded as either empty, sprung but empty, missing, or as a capture. For each capture, the species, age, sex, and number of individuals was recorded. Species were identified by a combination of fur color, size, and morphology.

Because *Sorex cinereus* Kerr (Masked Shrew) and *Sorex haydeni* Baird (Hayden’s Shrew) species are difficult to identify morphologically, we recorded them as *Sorex* spp. in the field.

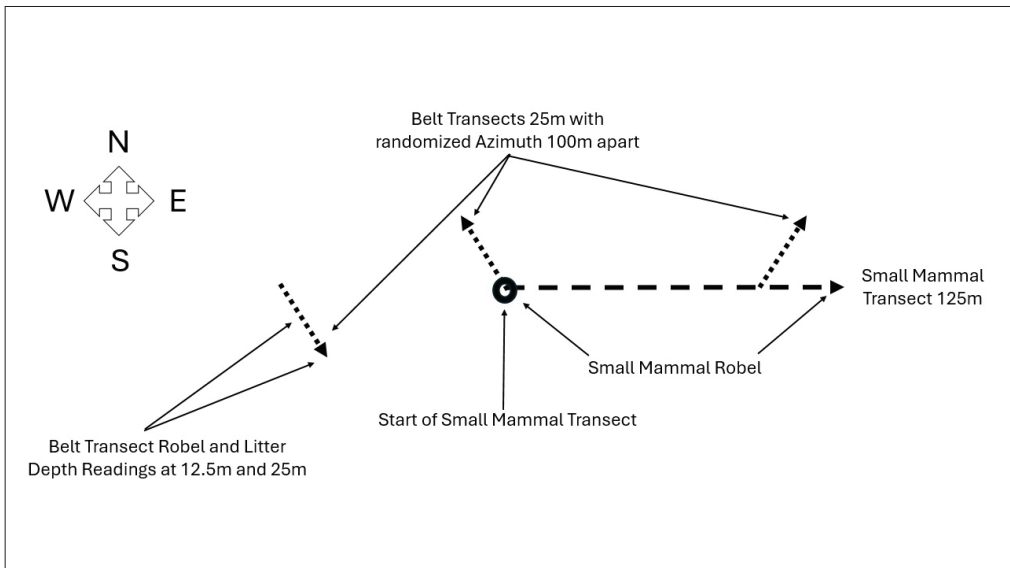


Figure 2. Layout of field sampling for all small mammals and vegetation at each of the 18 sampling points. The small mammal Robel survey (vegetation structure readings) was collected during each trapping season, including spring (2022), summer (2021, 2022), and fall (2021, 2022). The belt transects, which also included Robel and litter depth readings, were collected only during the summer of 2021 vegetation surveys to evaluate dominant vegetation types across the study area.

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However, in the event of trap mortality, specimens of *Sorex* were donated to a parasitology study in the Tkach lab at the University of North Dakota that was conducted on shrews, during which genetic identification could occur. All procedures involving handling wildlife were conducted under the appropriate permits and safety protocols (IACUC UND’s Institutional Animal Care and Use protocol 2103-3, Office of Laboratory Animal Welfare # A3917-01, North Dakota Game and Fish special use permits: GNF05508570 and OLN05753724, and USFWS special use permits: 62580-021-005 and 62580-022-003).

*Vegetation.* We conducted modified belt transects with Visual Obstruction Readings (VORs) using a Robel pole and litter depths (Robel et al. 1970; Grant et al. 2004). The belt transect method provides an efficient way to capture dominant plant groups. To evaluate vegetation characteristics across the study areas, 3 belt transects were conducted at 52 randomly selected survey points that were a part of a larger study. Three belt transects were conducted with 1 at the main point, 1 at a point 100 m north and another at a point

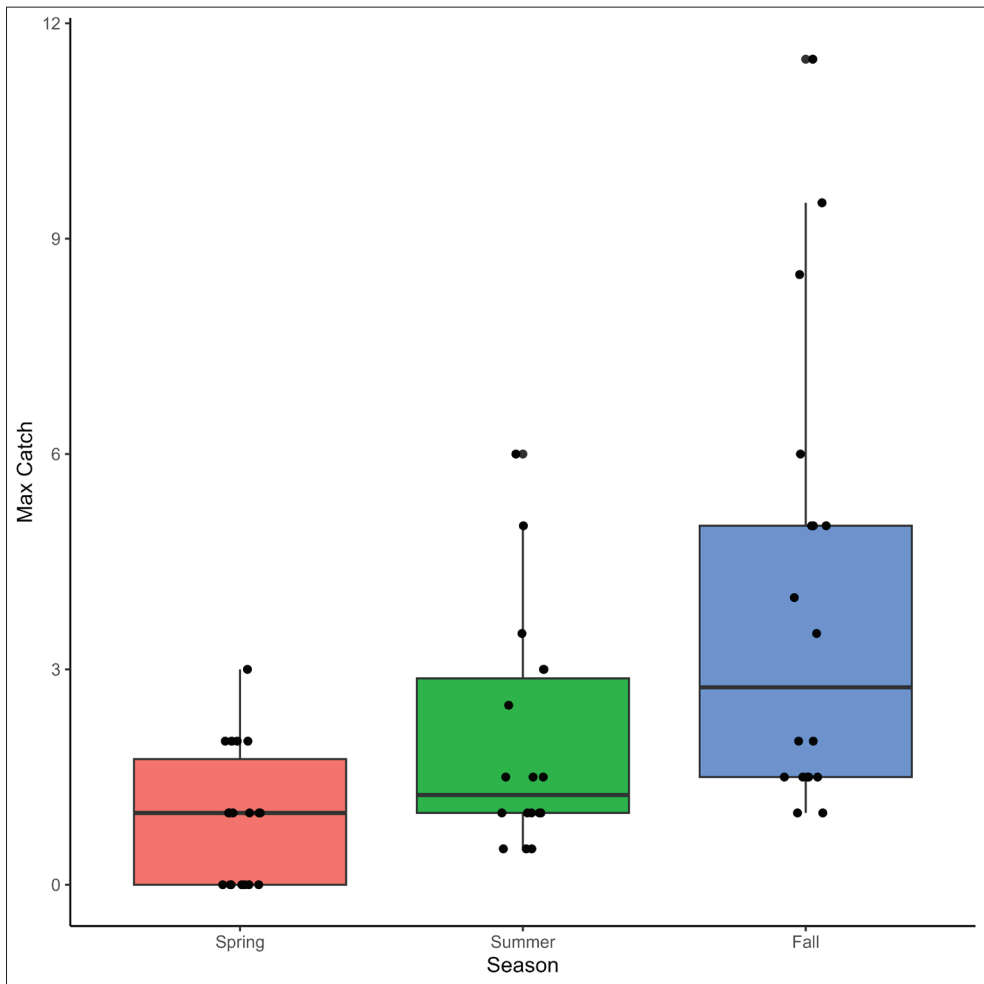


Figure 3. Max catch is the most individuals captured per trapping site for each trap check averaged across each season at GFAFB and the surrounding landscape in North Dakota (2021–2022). The outlier in summer and fall datasets was from a section that had been burned prior to surveys on Pender Waterfowl Production Area in the spring of 2021.

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100 m south of the main point, unless an obstruction was present (e.g., fences, property boundaries, open water, or other), in which case the 2 points were 100 meters east and west of the main point. For each of the 18 small mammal sites, the center belt transects intersected with the center of the trapline (Fig. 2).

Vegetation surveys were conducted in mid-to-late July when plants are easiest to identify (Gannon et al. 2013). Since vegetation composition typically does not vary substantially from year to year, we only did belt transects and litter depth in the first year (2021) of the study. At each transect we recorded the observer, date, slope, and the randomly selected azimuth. Dominant vegetation groups were based on the Native Prairie Adaptive Management (NPAM) initiative created by USFWS (Gannon et al. 2013). We recorded the dominant vegetation in half-meter segments within a 5-cm area on either side of the measuring tape over the 25-m transect (i.e., 50 measurements per transect). These transects were supplemented with VORs using a 1.65-m Robel pole (Robel et al. 1970) and litter depth to the nearest centimeter at the 15.5-m mark and the 25-meter mark of the belt transect, to provide information on vegetation structure. We recorded VOR in each of the cardinal directions and averaged the 4 readings. Additional VORs took place at the start and end points of small mammal transects at the time of each survey. This helped capture the source of seasonal and annual variation in plant structure (Robel 1970; Fig. A3).

### Data analysis methods

*Species captured and general analysis.* All data analyses were conducted in R (version 4.3.1) and R Studio (version 4.3.1). All figures were created with the *ggplot2* package (Wickham 2016), and Table 1 was created with *gt* package (Iannone et al. 2024). Summary statistics were collected to create a species inventory from captures.

*Small mammal use across treatments.* We defined maximum (max) catch as the most individuals captured per trapping site for each trap check. Trap checks were repeated across 2 years and 3 seasons, so we used the max catch averaged across year and season to analyze the potential differences between on- and off-base sites along with the 3 types of treatments (i.e., airfield, off-airfield on-base, and off-base). Because of kurtosis in the averaged max catch measurement, we used a non-parametric Kruskal-Wallis chi-squared test (alpha level  $<0.05$ , stats package, R Core Team 2023) to test for differences. When a difference was detected we conducted a post-hoc pairwise Wilcox test as appropriate (stats package, R Core Team 2023).

*Vegetation characteristics.* We compared vegetation across all treatments using averages of VORs and litter depths that were measured in the summer of 2021. With an absence of kurtosis, we conducted ANOVA tests (stats package, R Core Team 2023) to determine the main effects of treatment. We then calculated the mean percent of each of 4 vegetation types (native shrub/tree, native grass/forb, exotic grass/forb and noxious weeds, and other) across each treatment group to look for differences in composition during the summer of 2021.

*Impacts of season.* To test for differences in small mammal max catch and VOR between seasons we used averages across year, within season. Because of kurtosis in the averaged max catch and VOR, we used a non-parametric Kruskal-Wallis chi-squared test (alpha level  $<0.05$ , stats package, R Core Team 2023) to test for differences. When a difference was detected we conducted a post-hoc pairwise Wilcox test as appropriate (stats package R Core Team 2023).

*Capture rates relative to vegetation characteristics.* To determine if there was a correlation between averaged max catch and VOR, we used a partial Pearson's correlation, con-

trolling for the effect of season. The initial regression models were created with the stats package (R Core Team 2023) and included a main effect of season and random effects for the repeated measures of year and trapline. We then ran correlations of the residuals with the stats package (R Core Team 2023).

## Results

### Species captured

We had 622 individual captures of at least 11 species of small mammals at GFAFB and surrounding conservation areas (Table 1). Shrew mortality was high compared to other species groups (5 mortalities of 9 captures) due to their insectivorous nature and extreme metabolisms. *Sorex cinereus* and *S. haydeni* were confirmed genetically from the trap mortalities resulting in at least 11 unique species being identified. We did not differentiate *Peromyscus* spp. because we could not conduct genetic analysis on this genus of individuals. On-base we captured 10 of the 11 species and off-base we captured 10 of the 11 species. Most of the captures were Eastern Meadow Vole (40.7%) and *Peromyscus* spp. (33.4%). Most (73%) of the individuals were captured during the morning trap checks, compared to the late afternoon/early evening (Table 2).

### Small mammal use across treatments

Table 1. Summary of the small mammals captured by areas of highest to lowest bird strike risk across Grand Forks Air Force Base (GFAFB), North Dakota and surrounding landscape from the summer of 2021 to the fall of 2022. Because *Sorex cinereus* Kerr (Masked Shrew) and *Sorex haydeni* Baird (Hayden’s Shrew) species are difficult to identify morphologically, the 2 species were confirmed as part of a genetic and parasitology study in the Tkach lab at the University of North Dakota that was conducted on shrews and resulted in at least 11 species captured. *Peromyscus* spp. were not genetically tested to confirm different species.

Summary of Small Mammal Counts by Treatment

Mammal sp.	Airfield	Off Airfield	Off Airbase	Total
<i>Blarina brevicauda</i> Say	0	1	2	3
<i>Clethrionomys gapperi</i> Vigors	0	50	25	75
<i>Ictidomys tridecemlineatus</i> Vigors	35	6	12	53
<i>Microtus pennsylvanicus</i> Ord	32	145	76	253
<i>Mustela ermine</i> L.	0	4	1	5
<i>Peromyscus</i> spp.	28	59	121	208
<i>Poliocitellus franklinii</i> Sabine	0	0	5	5
<i>Sorex arcticus</i> Hutterer	0	1	0	1
<i>Sorex</i> spp.	2	4	3	9
<i>Zapus hudsonius</i> Zimmerman	0	7	3	10

We hypothesized that GFafb’s current habitat management would result in making small mammal use equal or less than the surrounding landscape. We found that the occurrence of small mammals, as measured by averaged max catch per trapline, was not different between on-base and off-base (Fig. A1;  $X^2 = 1.132$ ,  $df = 1$ ,  $P = 0.287$ ), nor was it different between the 3 treatment groups (Fig. A2;  $X^2 = 1.667$ ,  $df = 2$ ,  $P = 0.434$ ) when on-base sites were split between on- and off-airfield areas. Consistent occurrence throughout the landscape was noted with some variability within the treatments.

**Vegetation characteristics**

Using the summer 2021 vegetation data, we compared the 3 treatments to the VORs (Fig. A3) and litter depths (Fig. A4). We found that VOR ( $F = 0.466$ ,  $df = 2$ ,  $P = 0.630$ ) and litter depth ( $F = 0.751$ ,  $df = 2$ ,  $P = 0.477$ ) were not different across treatments. When examining dominant types of vegetation from the belt transects collected (Table 3), we found exotic grass/forb and noxious weeds are the most dominant type across all treatments. Therefore, vegetation was consistent across the landscape and dominated by exotic grass/forb and noxious weeds across our survey sites.

**Impacts of season on capture rates and vegetation**

We expected that small mammal abundance would increase over the summer due to reproduction, and found there to be a significant increase in the fall (Fig. 3;  $X^2 = 15.912$ ,  $df = 2$ ,  $P < 0.001$ ; spring–summer:  $P = 0.051$ , spring–fall:  $P < 0.001$ , summer–fall:  $P = 0.017$ ). We found a similar result in the vegetation structure data as measured by VOR with a difference between fall and the other seasons (Fig. 4;  $X^2 = 42.816$ ,  $df = 2$ ,  $P < 0.001$ ; spring–summer:  $P < 0.001$ , spring–fall:  $P < 0.001$ , summer–fall:  $P = 0.025$ ). In summary, small mammal occurrence and vegetation structure both increased over the summer as expected.

**Capture rates relative to vegetation characteristics**

We explored whether a correlation between averaged max catch and averaged VOR existed. However, since they were both impacted by season, we controlled for the potentially confounding effects of season observed in max catch and VOR using a partial Pearson’s correlation. We found that there was a significant, weak positive correlation (Fig. 5;  $R = 0.224$ ,  $df = 88$ ,  $P = 0.034$ ), suggesting that small mammal occurrence increased with vegetation height, independently of season.

Table 2. Summary of small mammal captures by time of day across the seasons of 2021– 2022 at Grand Forks Air Force Base in Grand Forks, North Dakota. Due to trap checks not occurring at sunrise and sunset for logistical reasons, this data should not be interpreted to reflect nocturnal versus diurnal activity of the small mammals.

	Time of Day	
Season	AM	PM
Spring	23	20
Summer	123	67
Fall	309	81
Total	455	168

**Discussion**

We evaluated small mammal capture rates and vegetative characteristics on and off a military airfield and across the larger complex landscape to provide information to help mitigate raptor collisions with aircraft. Given aircraft have the highest probability of a bird strike within an 8-km (5-mile) radius from an airfield (DeVault et al. 2017), it is important to evaluate areas beyond the airfield to better understand potential risk at the landscape level. For base management to meet goals of reducing strikes with raptors, they would want to manage the landscape such that the attractiveness of the base to raptors was less than or equal to that of the surrounding area.

**Species captured**

We captured 11 different species during our study, predominantly Eastern Meadow Vole and *Peromyscus* spp. A similar airfield study from Ohio examining small mammals and native vegetation resulted in capture of a similar number of species (10; Schmidt et al. 2013). However, our number of small mammal (11) species captured was almost double that of a previous study at GFAFB (6; Lafond et al. 2020). The same traps were used, and the habitat was not drastically different between studies. The primary difference in the small mammal species count may be explained by the larger area surveyed. LaFond et al. (2020) was restricted to areas experiencing mowing, haying, or no disturbance on-base, whereas our study included a variety of different management practices including mowing, haying, and burning, all located throughout the airfield, off-airfield, and even the surrounding landscape off-base. Excluding the off-base sites, we still captured 10 of the 11 species, with *Poliocitellus franklinii* Sabine (Franklin’s Ground Squirrel) species only captured off-base.

An area of potential interest for mitigation risk is identifying periods of highest small mammal activity related to time of day. While we do report captures by time of the trap check, we urge caution in interpretation of this data, given site access did not allow for checks to occur at sunrise and sunset and the opportunity to truly determine nocturnal vs diurnal activities. However, our morning trap checks likely reflect nocturnal and crepuscular activities that have been documented in *Peromyscus* spp. (Marten 1973) and *Microtus* spp. movements that may occur throughout the day, but are likely to be highest during crepuscular periods (Webster and Brooks 1981). Therefore, aircraft flights during those times when raptors may be actively searching for food may be of interest for future work where logistics permit an in-depth evaluation across seasons and weather patterns that influence small mammal energetics.

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Table 3. Summary of vegetation composition types at Grand Forks Air Force Base and surrounding landscape in Grand Forks, North Dakota. The belt transect surveys were conducted in 2021 at all 52 sites that were a part of a larger study at GFAFB.

**Proportion Summary of Vegetation Composition**

Vegetation Type	Airfield	Off Airfield	Off Airbase
Native Shrub/Tree	0.05	0.02	0.01
Native Grass/Forb	0.09	0.21	0.29
Exotic Grass/Forb and Noxious Weed	0.78	0.73	0.66
Other	0.08	0.04	0.03

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Each species of small mammal relies on unique habitat components. In our study and the previous study at GFAFB (LaFond et al. 2020) Eastern Meadow Voles were the most abundant species captured. This species is found most often in tall vegetation with litter present. They are deterred by woody encroachment and constant disturbance such as mowing, haying, and prescribed burns (LaFond et al. 2020). Given that most disturbance occurs on the airfield, this could explain why we found more voles in the off-airfield and off-base treatments. *Peromyscus* spp. were the second most abundant species, with a presence in all treatments except mowed areas, but the capture rate in each area varied substantially from trapline to trapline, similar to Lafond et al. (2020). At Pender WPA there was a prescribed burn conducted in the spring of 2021, prior to the start of our surveys. Once the vegetation was 40 cm, our team noticed increased trap detections of *Peromyscus*

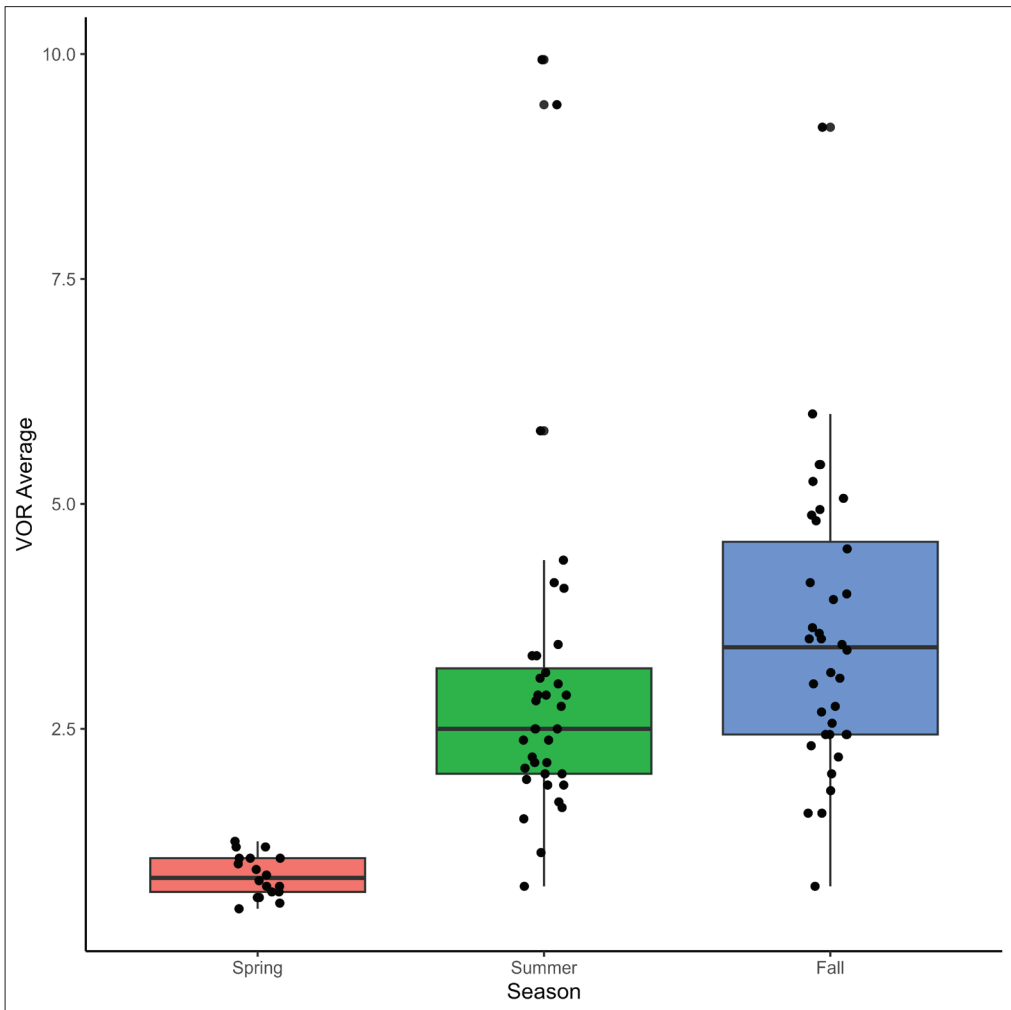


Figure 4. Visual Obstruction Readings (VORs) in dm across season at GFAFB and the surrounding landscape in North Dakota (2021–2022). The outliers in summer and fall datasets were from a section that had been burned prior to surveys on Pender Waterfowl Production Area in the spring of 2021, along with some of the unmanaged areas on GFAFB such as tree rows.

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spp. in the field, indicating that populations likely increased in numbers. It is worth noting that a given management action such as mowing or prescribed burns may deter 1 species of small mammal while promoting another, which is important to consider if the objective is to deter small mammals regardless of species.

Because our survey methods were focused on small mammals, we are limited in our ability to draw conclusions about how the abundance of other species may vary with management practices on- and off-base. One notable species that was missing from our surveys was *Urocitellus richardsonii* Sabine (Richardson’s Ground Squirrel), which we frequently observed on and around the airbase, but never captured. This is likely due to their size relative to our traps; our traps were not large enough for this species. We followed survey protocols previously done by LaFond et al. (2020) for comparisons.

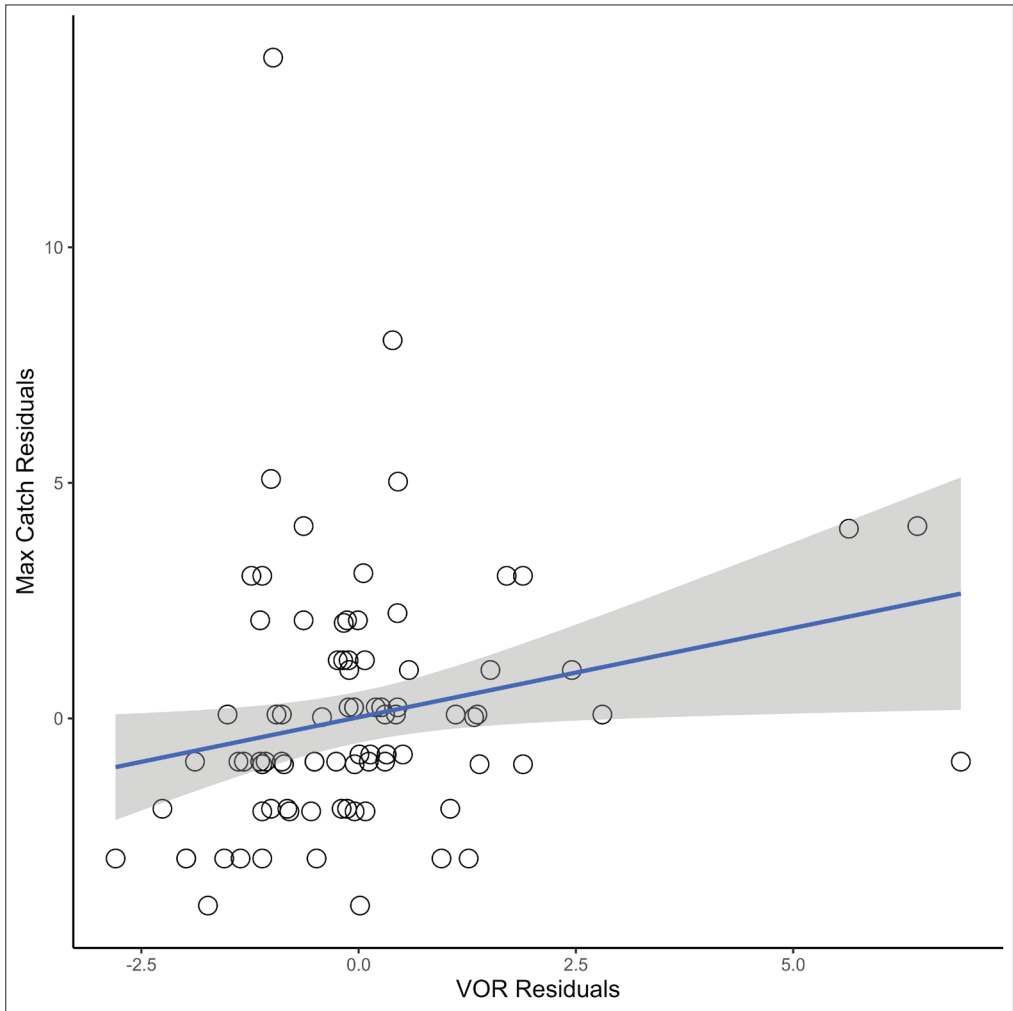


Figure 5. Positive correlation ( $R = 0.224$ ,  $df = 88$ ,  $P = 0.034$ ) between the residuals from the partial Pearson’s correlation of the maximum catch of small mammals per trapline and the Robel/Visual Obstruction Reading (VOR) at GFAFB and the surrounding landscape in North Dakota (2021–2022). The max catch residual outlier is from the prescribed burn section of Pender Waterfowl Production Area, and the VOR residuals are from unmanaged areas of GFAFB.

Future inventory studies wanting to include this species in their evaluations should use Sherman live traps with a height and width of 12.7 cm × 12.7 cm (5 in × 5 in) instead of 7.62 cm × 8.89 cm (3 in × 3.5 in).

### **Small mammal use across treatments**

We hypothesized that captures would differ on- and off-base and by treatment due to different management regiments. Our results did not support this hypothesis; however, the lack of statistically significant differences does not necessarily mean that bird strike risk is the same on and off the airfield. Instead, no differences suggest that there may be equal attractiveness for raptors based on the availability of the types of prey that we surveyed. At the very least, small mammal capture rates should be higher in unmanaged areas than in managed areas. The highest capture rates were observed to occur in the off-airfield areas on-base. Furthermore, although most of the urbanized areas off-airfield but on-base receive frequent lawn mowing, some of these areas are not heavily disturbed; at 1 of our trapline transects there is a restored prairie area with walking trails which likely promotes small mammals.

Due to a variety of logistical challenges, we were only able to sample 18 total transects. Another logistical limitation to this study is that we did not survey urban areas of the base (i.e., areas with housing or other facilities with high human use) which would have better determined small mammal use across the entire base. Some areas away from most of the human development are managed by haying or prescribed burns. In contrast, the airfield receives substantial disturbance with mowing to 17.8–35.6 cm (7–14 in) vegetation height and even shorter close to the runway (BASH GFAFBI91-212 2019). The conservation areas in the surrounding landscape only receive prescribed burns, and the amount of disturbance depends on the management organization (NDGF, USFWS, and UND), based on individual site priorities (e.g., Mekinock vs. Pender WPAs). Our results suggest that even though there is difference in land management among agencies small mammal use is similar across the landscape.

### **Vegetation characteristics**

We hypothesized that the vegetation characteristics would be different among the treatments given different objectives across the landscape for land management, but we found no statistical differences. We found that the vegetation across the landscape is lacking in diversity and is generally dominated by exotic grass/forb and noxious weeds ( $\geq 66\%$ ); Table 3). This cover class was comprised primarily of the invasive grasses *Bromus inermis* Leysser (Smooth Brome), *Poa pratensis* L. (Kentucky Bluegrass), and *Euphorbia esula* L. (Leafy Spurge). Once established, these species are difficult to reduce and can have a variety of impacts on wildlife use (Ellis-Felege et al. 2013), perhaps altering both local small mammal species assemblages and populations.

### **Impacts of season**

We hypothesized that there was an effect of season on small mammal reproduction and vegetation growth and found that there was an increase in vegetation height and small mammal abundance occurring spring–fall. This provides an increased amount of prey availability. Most bird strikes occurred in later summer (July: 8 strikes, August: 5 strikes) when the vegetation height and structure were likely at their peak, reproduction had occurred for the season, and early migrants were beginning to move (Kuechle 2020). As a result, it is important to consider seasonality in management practices when attempting to deter bird strikes.

### **Capture rates relative to vegetation characteristics**

After controlling for the effect of season, we found a positive correlation between small mammal capture rates and vegetation structure. The correlation is weak but is still a statistically significant finding. This result could be due to a variable not included in our analysis, but it was similar to Schmidt et al. (2013), who found that increased vegetation structure correlates with an increased number of small mammals. Given that the summer to fall transition (i.e., July–September) is not only when the most bird strikes occur (Kuechle 2020), but also the period of the highest small mammal occurrence and tallest vegetation structure, we advise that the designated habitat management (mowing, haying, burning) should be focused on this time of year. However, it is noteworthy to consider that Schmidt et al. (2013) proposed the idea that even though raptor prey availability does increase with vegetation structure, the accessibility of capturing that prey may also become more limited with increased structure. Because we only surveyed prey availability and not specifically raptor use, we can only relate our small mammal and vegetation results. However, this is an important consideration when determining management actions.

### **Conclusions and Management Implications**

Coordination of management across the complex landscape could provide benefits to reduce bird strikes, given most bird strikes happen within 8 km of an airfield (DeVault et al. 2017). When managing competing interests it is crucial to find a balance, such as creating a base environment that is less than or equally attractive to that of its surroundings, to avoid birds congregating near the airfield. Therefore, collaborative vegetation management beyond the immediate airfield should be considered when possible. When considering habitat management priorities, seasonality is an important factor to consider for small mammals, vegetation, and raptor/bird abundance since these appear to vary across the seasons. Late summer to fall habitat management may provide the most benefits of reducing raptor collisions with aircraft based on small mammal availability. If deciding to use prescribed burns, ensure there is post burn management as well, to prevent an increase in *Peromyscus* spp. as anecdotally observed within our outliers. While our study focused on small mammals and their associated habitats as attractants for raptors, there are many alternative habitat options to decrease raptors beyond prey availability. Removal of roost and nesting trees may provide an alternative habitat solution. On a prairie landscape, removal of trees and woody encroachment that could serve as nesting and roost sites to raptors is generally a favorable prairie management tool that multiple stakeholders on the larger landscape may embrace, and that could provide a mitigation approach for aviation safety that warrants further investigation. In short, managing airfields to minimize their attractiveness to avian species requires considering the broader landscape (Blackwell et al. 2013). We found in our study that the military airfield's management did not increase the use of small mammals that might attract raptors when examining the landscape. However, the fall season was the period with highest activity, and associations with taller vegetation may also provide opportunities to manage vegetation so that it reduces small mammal use, and ultimately, attractiveness to raptors that pose a risk to aviation safety.

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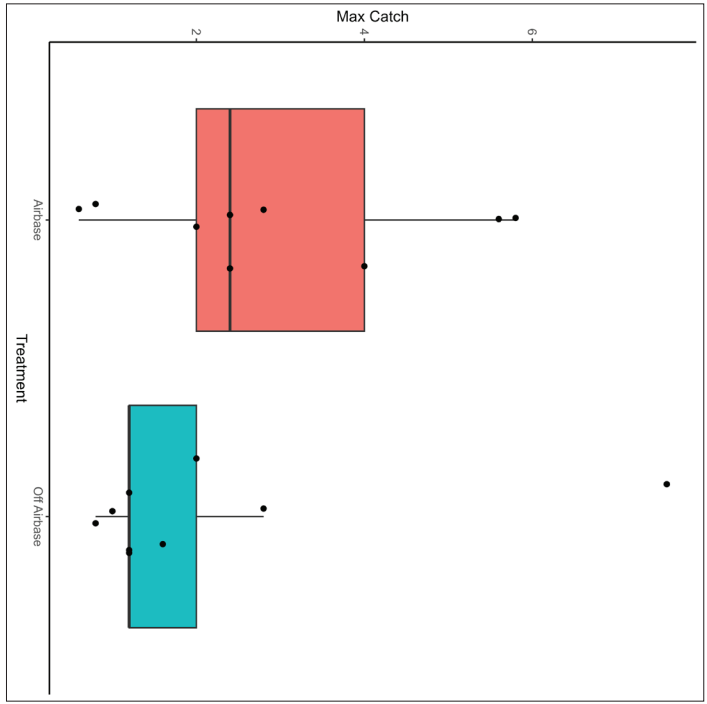
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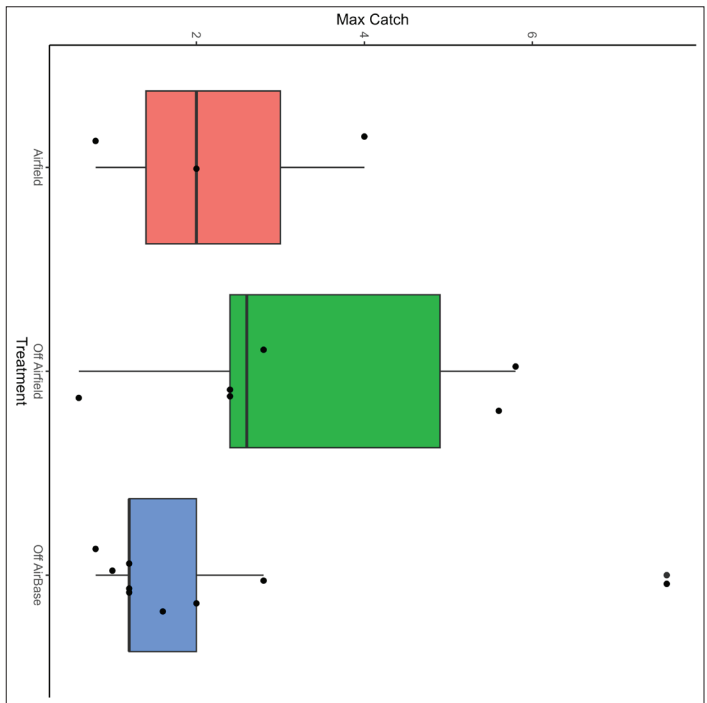
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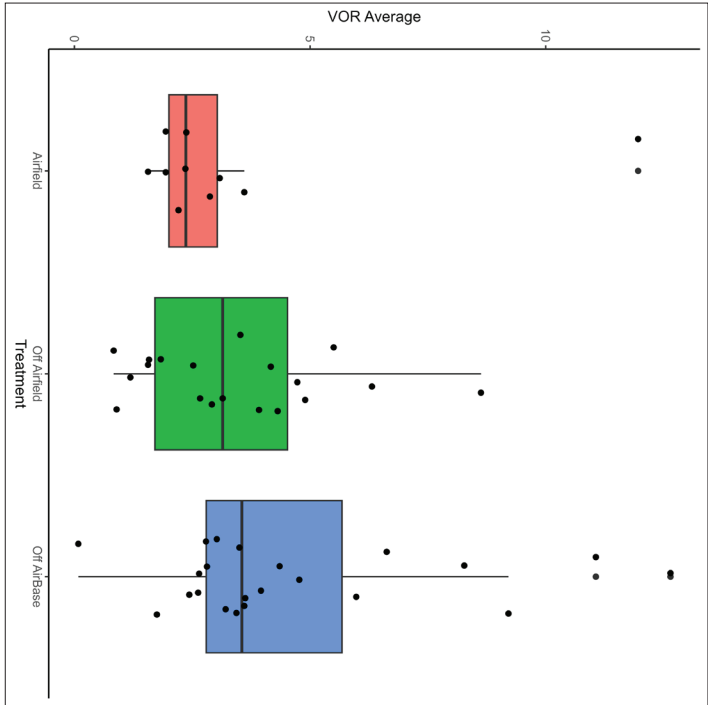


Appendix A1. Evaluation of on- and off-base max catch per trapline of small mammals sampled at Grand Forks Air Force Base (GFAFB) and the surrounding landscape (2021–2022). The outlier in the off-airbase treatment was from a section of Pender Waterfowl Production Area that had been burned prior to surveys in the spring of 2021.

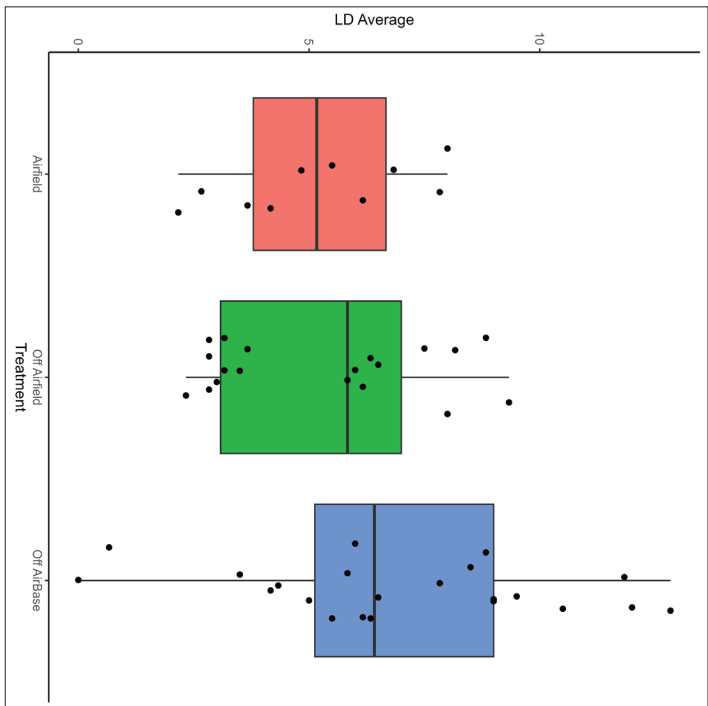


Appendix A2. Small mammal max catch per trapline across the airfield, on-base off-airfield, and off-airbase at GFAFB and the surrounding landscape (2021–2022). No statistical differences were found and the outlier in the off-airbase treatment was from a section that had been burned on Pender Waterfowl Production Area prior to surveys in the spring of 2021.

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Appendix A3. Visual Obstruction Readings (VORs) in dm across treatments of on-airfield, off-airfield but on-base, and off-airbase at GFAFB and the surrounding landscape in North Dakota in July 2021. The outliers in the on-airfield treatment are in the non-mowed areas within the airfield perimeter fence.



Appendix A4. Litter depth (LD) in cm across treatments of on-airfield, off-airfield but on-base, and off-airbase at GFAFB and the surrounding landscape in North Dakota in July 2021. The off-airbase outliers were from a section in Pender Waterfowl Production Area that had been burned prior to surveys in the spring of 2021.