Improving efficiency of prairie dog surveys by using a small copter drone

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Sponsor: City of Boulder Open Space and Mountain Parks (OSMP)

Final version submitted: January 26, 2022

Abstract (300 words maximum)

Prairie dogs (*Cynomys ludovicianus*) are an accessible and enjoyed wildlife species in Boulder that require occasional survey because populations can change due to plague outbreaks or human-induced control. We evaluated the use of small copter drones at four prairie dog colonies on OSMP lands, Boulder, to determine if this methodology improves efficiency over ground-based survey methods. We counted prairie dogs and burrows using two types of drones (DGI and Autel) at altitudes 100', 150', and 400' (burrows only). We recorded video and merged still images into a mosaic prior to having USDA staff analyze this imagery. We then compared the drone imagery counts to those of our simultaneous ground-based counts of prairie dogs. We determined that 100' altitude mosaics produced using DGI drone were most accurate (closest to true, ground-based counts) for burrow abundance and generally so for prairie dog abundances. Video vs. mosaic had similar accuracy in most prairie dog counts, and 150' video was more accurate than 100' video. One staff member counted burrows more closely to true than did the other. Both staff members required about the same amount of time to count/analyze imagery; videos could be evaluated slightly faster than mosaics (average of 3.8 hours vs. 5.5 hours per imagery), and burrow counts (of mosaics) generally took 2-3 times longer to analyze (averaging 8.1 hours per imagery; range: 3-13 hours) than did prairie dog counts. The labor requirement of using drones for burrow and prairie dog counts is far more time consuming (3-4 times longer per hectare) than having field staff conduct the traditional on-the-ground counts that include repeated prairie dog counts in a day. Until technology improves and target colonies are very large (>2 km^2) or inaccessible, drone surveys are unlikely to be a more efficient technique than ground-based surveys for evaluating prairie dog abundances.

Keywords: black-tailed prairie dogs, burrow density, Colorado, *Cynomys ludovicianus*, drone survey technique, ground-based surveys, methods comparison, Unmanned Aircraft Systems, wildlife damage management

Introduction

Prairie dogs (*Cynomys* spp.) are often enjoyed by the public, as they are some of the most accessible native wildlife in North American prairies, and they are often integrated within cities and city edges where recreationalist commonly visit (Hoogland 2002). All five prairie dog species, including the black-tailed prairie dog (*Cynomys ludovicianus*) of the Colorado Front Range, are species of conservation interest (Hoogland 2002). Property damage from prairie dog burrowing and chewing behaviors is common in urban and natural environments (VerCauteren et al. 2010), and clipping vegetation (cover reduction) for food and nesting material occurs around the vicinity of burrows in agricultural and natural areas (Hygnstrom and Virchow 1994). Prairie dogs also serve as reservoirs for sylvatic plague (Hygnstrom and Virchow 1994), and populations in urban areas can increase plague transmission to pets (Witmer et al. 2000). Additionally, re-establishment of black-footed ferret (*Mustela nigripes*) populations may be hampered by plague outbreaks in prairie dogs (Hoogland 2002).

Because of the array of human-prairie dog conflict issues, it is understandable how prairie dog management is controversial. Damage management techniques include habitat modification (e.g., deferred grazing), exclusion, fumigants, toxicants, traps, and shooting. Many land stewards in Colorado's Front Range, including City of Boulder Open Space and Mountain Parks (OSMP), prefer not to use lethal control to manage prairie dog problems, and OSMP's past and present priority research areas have included pursuit of non-lethal methods for prairie dog control. In our recent studies, we (USDA/NWRC) have tested GonaCon contraceptive for this purpose (see Shiels et al. 2020). A key component to measure efficacy of any prairie dog management technique is an efficient and effective method for estimating population density. A rapid and reliable method for which prairie dog populations can be surveyed is important for land managers, such as those at OSMP. Traditional survey methods (e.g., binoculars, live-trapping) can be labor intensive, and biased in detection rate and capturing only a subset of the population. Mark-and-recapture is more labor intensive than visual count surveys (Merkens et al. 1990). Because prairie dogs create discrete mounds surrounding their burrows, researchers have attempted to correlate burrow densities with prairie dog densities; however, Hoogland (1995) concluded that mound densities were not a good predictor of prairie dog densities. In our study, we tested the use of small copter drones (Unmanned Aircraft Systems) as a tool for improving efficiency of prairie dog surveys. Drones have been used to survey a variety of wildlife and wildlife damage (Fischer et al. 2019), including counting burrows of prairie dogs in Colorado (Hasan 2019 [graduate thesis]). Using drones to estimate prairie dog densities and comparing such estimates to traditional methods (e.g., visual survey counts, burrow densities) has not been studied to our knowledge, but such a comparison could greatly improve efficiency of prairie dog estimates and save land managers money.

The main objective of our study was to test the effectiveness of using a small copter drone to both estimate prairie dog density and to compare the drone estimates to simultaneous ground-based count surveys. We have an experienced drone operator on our USDA staff (Justin Fischer) who has all the necessary certifications and equipment to complete such flights and perform post-field analysis; he has extensive experience using drones in similar contexts (e.g., estimate feral pig damage to agriculture; Fischer et al. 2019; assisted in pilot study in Ft. Collins with Shiels et al.). To make our assessment as informative as possible to land managers considering using drones for such prairie dog surveys, we will not fly below 100', as this altitude was determined in our 2020 pilot study in Fort Collins as an appropriate threshold to prevent disturbance to prairie dogs while obtaining accurate prairie dog counts. We note our flight speeds, width of overlap scans, time of day, and viable camera types (e.g., preferred zoom, and picture mosaic vs. video). Given these flight characteristics, we determine whether we can distinguish prairie dogs using the drone imagery, whether burrow density can predict prairie dog abundance, and the human hours or economic costs associated with such surveys. This information will help guide OSMP decision making on whether to consider the use of this technology and methodology in the future. With drone use as a prairie dog survey technique that may be less labor-intensive and cheaper than traditional methods, we anticipate that our findings will receive widespread interest as a modern survey method available for land owners and managers in Boulder, the Front Range of Colorado, and more broadly throughout the grasslands of North America.

Methods

Study sites

Our study occurred at four prairie dog colonies (sites) on City of Boulder Open Space and Mountain Parks (OSMP) lands, Boulder, Colorado, and these sites were chosen after consultation with OSMP staff (particularly Victoria Poulton). The four sites are listed below with their sizes that were surveyed for this study (each site 6-10 acres [2.4-3.9 ha] surveyed by drone and from the ground): Gilbert North (3.84 ha), Gilbert South (2.42 ha), Johnson North (2.89 ha), Waldorf (3.77 ha) (**Table 1**). The boundaries were delineated with pin flags and a hand-held GPS unit—the pin flags were visible in all drone imagery so that ground- and drone-based counts would be consistent. All candidate sites were confirmed as being far enough from airports to fly safely and legally using our drones.

Drone methodology and prairie dog imagery for density estimates

We used our 2020 findings of altitude, flight speeds, and best times of day to fly from three Fort Collins prairie dog colonies to guide our flights over Boulder lands. These included appropriate drone height (100-150', as lower heights would substantially disturb prairie dogs), flight speed (4-12 mph), and width of overlap scans (63' wide at 150' altitude; 38' wide at 100' altitude during video recording; 70% overlap for all still photos that would make up the orthomosaic). All daytime hours were acceptable 'times of day' for our surveys as long as wind speeds were low (e.g., sustained winds <20 mph). We had USDA personnel observing prairie dog behavior while the drone was in flight to ensure flight altitudes and speeds minimally disturb prairie dogs. Common prairie dog alarm behaviors include: raising to hindlegs, distinct (alarm) vocalizations, retreat to burrow entrance, and retreat underground in burrow. If significant disturbance to the prairie dogs had occurred from the drone flying overhead, which is indicated by prairie dogs suddenly and directly retreating to burrows, our protocol stated that we would land the drone and reprogram our subsequent flights so they were at altitudes where significant disturbance was no longer detected (i.e., increasing altitudes at 25' increments until such minimal disturbance was realized). Separate flights were necessary to record video and still images because the overlap distances were different between video and still imagery. All of the proposed methods were reviewed and approved by USDA's Institute of Animal Care and Use Committee (IACUC) under protocol QA-3353.

To further ensure that drone disturbance was minimized for prairie dogs, launch locations and ground-based observations occurred from at least 100’ outside of the survey area; thus, the drone reached the 100’ minimum altitude by the time it is no closer than 100’ from the survey area. We used two different drones, and each drone has its own camera. The drones and cameras were: 1) Autel Evo II (Certification number: FA3CHMP34W), fixed with a Sony IMX586 camera (48MP), and 2) DJI Matric 210 (Certification number: FA3A799PCY), affixed with both a Zenmuse X4S (20MP) and a Zenmuse Z30 (30x optical zoom). These are common ‘over-the-counter’ and affordable types of drones that land managers could easily purchase; Autel with camera is ~$300 whereas DJII with both cameras costs closer to $10,000 with the listed opticals and batteries.

After choosing the drone and appropriate altitude, speed, and swath width, a drone flight plan for each site was developed and programmed using mapping software. Based on previous flights with these drones at the anticipated flight speeds (4-6 mph with DGI) and altitudes, batteries must be switched out approximately each 30 minutes, and two battery changes are needed for each hectare of flight imagery. Once the drone ‘returns home’ to land, batteries are switched out, and the drone is launched and immediately flies to the location on the transect where it left off prior to the battery change. The pilot ensured that the flight plan was followed and that the drone flew the entire target portion of the prairie dog colony. At the end of each week of flying, the details of each flight and any interactions with humans or wildlife at the site were reported to OSMP. Different altitudes result in great variation in flight time and the number of pictures necessary to survey a prairie dog colony. For example, for Waldorf (3.77 ha), 100’ altitude took 38 minutes (which included two landings for 1-3 minute battery changes) to capture the 620 pictures to survey the colony, whereas 400’ altitude took 7 minutes (no battery changes) and included just 64 pictures to survey the colony. There was 3 cm resolution per pixel for each of the 100' and 400' altitudes with the DGI drone and optic.

Once field imagery had been recorded, there were three readily available software programs that were used in our analysis. The software programs used were: ArcMap, Drone2Map, and Google Earth Pro. These software programs enabled two types of imagery to be viewed to identify and quantify prairie dogs and their active and inactive burrows. The first type of imagery resulted from the drone flying transects and taking still-photos at set intervals. The Drone2Map software then stitches the photos together, using many points of reference from overlapping images to create a single image that we call a mosaic. Personnel at USDA can then count prairie dogs and burrows on the mosaic. The second type of imagery was video, and the DJI Matric 210 drone had an optical that could zoom up to 30x. After the drone flew all transects and we ensured it adequately covered the colony by viewing the real-time recording in the field via a laptop, USDA personnel transferred the imagery to USDA servers and counted prairie dogs and burrows from their offices by watching the video. Double counting prairied dogs where transects overlapped or when prairie dogs move to-and-from the edges of the field of view was avoided whenever possible. All imagery analyzed was reported in association with the drone type, optics, altitude, flight speeds, width of overlap scans, and time of day used to gather the imagery. These characteristics were then used to compare to ground-based counts (see below) to determine which drone types, altitudes, and imagery fit closest to the ground-based counts and how each drone analysis time requirement was most economically efficient

Ground-based prairie dog population and burrow density estimates

Visual counts of prairie dogs were made simultaneously with drone flights. Prior to conducting counts, each personnel had to prove that they could successfully identify artificial prairie dogs (bottles painted to mimic prairie dogs; Menkens et al. 1990) of juvenile and adult sizes, placed at each research site (see Severson and Plumb 1998). Prairie dog counts were then performed from 100 feet outside the prairie dog colonies to reduce disturbances, and the observers were always stationed at elevated sections of the landscapes (e.g., a hill). Arrival of personnel at the study site invariably results in animals seeking refuge in their burrows, so counting did not commence until 'undisturbed' prairie dog activity resumes (~15 min). To count the animals, plots were scanned with binoculars starting at one end of the plot and proceeding to the other end. There were two sets of prairie dog counts at each site; one set occurred simultaneously during drone flight and were in the same direction and with the start and end points of the drone flights, and a second set occurred when the drone was not flying (both before and after each drone flight). It should be noted that on-the-ground counts only took about 10 minutes to complete, whereas drone flights over the same area would often take >30 min; this made 'simultaneous' comparisons of the two methods inaccurate. Therefore, the second set of prairie dog counts were our best estimates of the true prairie dog density at the site, and it included multiple counts spaced at least 15 minutes apart at the following two time periods: morning (7:30am-10:30am) and midday (11:00am-1:30pm). Each morning and midday count at each site consisted of at least three counts (pre-drone flight, during drone flight, and post-drone flight) by each of two observers. This resulted in at least 12 independent counts of adults and juveniles per site. However, for each site, the highest counts for juveniles and adults were used for analysis, as this favors determination of the minimum number of individuals known alive (MKA) for each site.

Prairie dog burrows were also counted, and correlation analysis of burrows and prairie dogs occurred for ground-based and drone-based methods. For ground-based methods, each burrow (mound) was counted using temporary pin-flag markers, as well as classified as active (i.e., fresh soil disturbance and/or fresh feces in the entrance) or inactive. Active and inactive burrows were combined for analysis. Population sizes (MKA) and burrow densities were calculated for each of the four sites.

Results

Drone surveys of prairie dogs and comparisons to ground-based surveys

During analysis of videos and mosaics at all altitudes flown, we could not distinguish between juvenile or adult prairie dogs; therefore, we report our prairie dog counts as total individuals rather than attempting to separate by size class (**see Appendix 1-2**). Although the accuracy of the drone-based counts and ground-based counts varied among sites (**Tables 2-5**), the most noticeable difference occurred with early summer counts versus late summer counts. Waldorf was the only site that was counted twice—once in early summer (June) and once in late summer (August). The June counts were widely different than the August counts for both drone-based and ground-based counts (**Table 2, Table 3**), as the vegetation was thicker and up to 1 m tall in June whereas August had sparse vegetation cover that was generally no higher than 30 cm height. The June survey resulted in further analytical difficulties as the imagery for the mosaics was reported to be very blurry in several locations. A clear recommendation from this seasonal comparison is that counts will be easier and more accurate if conducted during the late summer, and all of our remaining observations thus occurred in late summer (mid-July-August).

The mosaic did not fully form for the northwest corner of Gilbert North, so staff had to go through the individual images for that corner of the site to best count the prairie dogs. The Autel flew noticeably faster than the DGI when capturing still photos, and Autel needed fewer (or none) of the battery changes relative to the DGI. Prairie dogs were noticeably aware of the drone hovering and flying at altitudes 100’ and 150’, yet at 400’ they did not appear to be aware of the drone. However, one additional note here is that 400’ altitude was always flown after either a 100’ or 150’ altitude on the day of drone surveying the site, and prairie dogs could have already been accustomed to the drone and the ground staff in the area upon flying at 400’. We completed 400’ flights with Autel drone but the imagery was so poor (blurry) that ground/rocks could not be distinguished from prairie dogs—none of the 400’ flights with Autel were reported here.

The counts using the drone imagery were compared to the ‘true counts’ using the ground-based surveys for both estimates of prairie dog individuals and burrow densities. Therefore, we report the raw counts using drone imagery for individuals counted (**Table 2**) and burrows counted (**Table 3**), as well as the different from ‘true counts’ (**Table 4** and **Table 5**). Video vs. mosaic had similar accuracy in some prairie dog counts, and 150’ video was more accurate than 100’ video. One staff member counted burrows more closely to true than did the other. We determined that 100’ altitude mosaics produced using DGI drone were most accurate (closest to true, ground-based counts) for burrow abundance and generally so for prairie dog abundances (**Tables 2-5**).

Ground-based prairie dog population and burrow density estimates

The four Boulder sites used in this study had mean (SE) prairie dog densities (using MKA methodology described above) of 14.4 ± 2.4 individuals/ha and prairie dog burrows of 161.0 ± 21.2 burrows/ha. A correlation test was performed in R (version 3.4.1) statistical software with burrow density and prairie dog density. The correlation was not significant (P = 0.5257, df =2, t = 0.76189, R^2 = 0.2249). When the four Boulder sites were combined with seven prairie dog sites (using the same methodology) measured in 2020 in Fort Collins and Denver, burrow density was significantly correlated with prairie dog density (P = 0.02358; **Appendix 3**).

Time requirements for each step of prairie dog surveys using drones or ground-based methods

Time requirements for each step of prairie dog surveys are important for establishing efficiencies of methodologies. The key steps used to complete prairie dog surveys in our study included: **1) field collection**: included drone flights or on-the-ground surveys. In our case we flagged the boundaries with GPS to make a more efficient flight plan in Google Earth and aid in on-ground counts, which took 1 hour with 2 people. However, the bulk of the field collection efforts were the drone flights and on-ground counts. **2) download imagery**: whereas video is a single file, the mosaics are formed by stitching all the still images together using Drone2Map software (Esri product). This software is free to government employees. It takes a standard computer (like Justin Fischer's used in this study) 12+ hours to make a mosaic using the Drone2Map software when there are 300 or more still pictures involved. Although 400' altitude flights generally had <100 pictures to complete the mission, the 100' had 510 pictures at our smallest site (Gilbert South) and at our two largest sites there were 750 pictures (Waldorf) and 722 pictures (Gilbert North). The 150' had 229 pictures at Gilbert South and 373 pictures at

Waldorf. **3) analyze imagery**: videos could be evaluated slightly faster than mosaics (average of 3.8 hours vs. 5.5 hours per imagery), and burrow counts (of mosaics) generally took 2-3 times longer to analyze (averaging 8.1 hours per imagery; range: 3-13 hours) than did prairie dog counts (**Tables 6, Table 7**). Examples of mosaics and videos are shown in **Appendix 1-2**. Both staff members required about the same amount of time to count/analyze imagery. The labor requirement of using drones for burrow and prairie dog counts is far more time consuming (4.9-5.4 hours/ha for prairie dog counts, and 6.2 hours/ha for burrow counts) than having field staff conduct the traditional on-the-ground counts (<4 hours with two people for repeated prairie dog counts or single burrow counts; or at rates per person of <1.2 hours/ha for on-ground prairie dog counts and for burrow counts for 1 person they are 0.6-2.2 hours/ha) (**Tables 6, Table 7**). In short, it took 3-4 times as many hours to count prairie dogs or burrows using drones (field work+download imagery+analyze imagery) as it did to conduct on-the-ground surveys (solely fieldwork with repeated prairie dog measurements in a day, and based on one person conducting all counts).

Discussion

Using drones to capture prairie dog and burrow imagery while conducting simultaneous ground-based counts has provided the opportunity to compare two methods for surveying prairie dogs across various landscapes. While small copter drones have been used to successfully detect large game or wildlife species and their damages (Fischer et al. 2019), or haze pest wildlife in farmlands or near airports (Wandrie et al. 2019, Pfeiffer et al. 2021), prior drone use for prairie dogs has been limited to burrow identification to help determine colony boundary limits and dynamics (Hasan 2019). Here we have shown that small copter drones can be successfully used to collect imagery from prairie dog colonies that enable estimations of abundance and burrow densities. We have identified safe flight altitudes that limit disturbance to prairie dogs, as well as altitudes that can be used to successfully detect individuals and burrows. In our comparison of methods, we demonstrate that while drones can be used for prairie dog surveys, they are less efficient (due to staff time required) than using traditional ground-based methods where field staff visit colonies to conduct multiple counts.

Establishing minimum altitudes that prairie dogs can be detected with drones while minimizing prairie dog disturbance was one of the initial challenges of pursuing drone-based surveys. By using multiple human observers equipped with binoculars and having counted and observed prairie dog behaviors prior to launching drones, we were able to determine the minimum altitude that prairie dogs perceived drones as risky. The lowest altitude with minimal and acceptable disturbance to prairie dogs was 100’ (~30 m), and both 100’ and 150’ overhead flights caused some prairie dogs to initially retreat to burrows but not disappear into their belowground burrows. Most of the observed behaviors at 100’ and 150’ altitudes included temporarily halting of their activities (e.g., feeding, moving, socializing) for several seconds until the drone had apparently been perceived as low risk or threat. In a drone study with red-winged blackbirds, the 100’ altitude was determined to be more of a threat to these birds than the 150’ altitude (Wandrie et al. 2019). One confounding factor for this comparison was that the 100’ altitude used a DGI small copter drone like the one used in our study, yet the 150’ altitude used a fixed wing drone (Wandrie et al. 2019). One advantage of considering a fixed wing drone for future prairie dog surveys is that they have a much longer battery life than the small copter drones that we used, and our drone pilot Justin Fischer discovered that fixed wing drones that he uses could fly for 1 hour in similar conditions as maintained in our study without battery changes (i.e., the fixed wing doubling the capabilities of the DGI copter drone). However, a downside to the fixed wing drones is that they more closely resemble birds of prey or otherwise have been perceived as a greater risk to wildlife than the small copter drones (Egan et al. 2020). As a final note on drone types, our ground staff felt that the Autel drone was perceived as slightly riskier to prairie dogs than the DGI used during our study, perhaps because the Autel more closely resembles a raptor in flight or size.

The 100’ altitude mosaics produced using DGI drone were most accurate (closest to true, ground-based counts) for burrow abundance and generally so for prairie dog abundances; therefore, this altitude and configuration is recommended for individual and burrow counts. The 100’ mosaics were the slowest to fly because of the high frequency of the drone needing to stop and take still pictures, as the 100’ altitude was the closest to the ground (i.e., narrowest field of view) relative to the other two altitudes flown. The 100’s of still pictures increased processing time needed to stitch the pictures together using various frames of references (e.g., rocks, bushes, hills) to create the single mosaic in the Drone2Map program. The greater the altitude, the wider the frame of view and therefore fewer pictures were needed to capture the entire prairie dog colony. Fewer pictures also resulted in fewer drone stops during each flight and in some cases no battery changes were required to fulfill the mission of recording imagery across the target prairie dog colony.

Video vs. mosaic had similar accuracy in prairie dog counts for some colonies, but two (Gilbert North and South) of the four colonies proved much less accurate (2-3 times worse) when prairie dogs were counted using video imagery than conducting mosaic counts (**Table 4**). Based on analysis of our two staff members that were counting prairie dogs using the two forms of imagery, counts of prairie dogs using video imagery can be either faster or equivalent to counts conducted using the mosaics (**Table 6**). If video imagery from drones is used, we found that it was more accurate in counting prairie dog individuals from 150' altitude than 100' altitude. One additional benefit of using mosaics rather than video for prairie dog surveys is that both individuals and burrows can be counted using the same mosaic, whereas videos are not recommended (nor used in our study) for attempting to count burrows.

We had hoped that 400' flights would be adequate to accurately detect prairie dog burrows, and that burrows density would have a correlative relationship with prairie dog density. We only found such a correlative relationship when the four Boulder sites were combined with seven sites from Fort Collins and Denver. The 400' flights were the fastest to fly and never required landing for battery change. The large field of view at 400' altitude enabled the fewest number of pictures to record the imagery for the entire colony, and that imagery was later stitched together to form the mosaic. Unfortunately, 400' flights obscured the ground imagery enough that prairie dog burrows could not be dependably distinguished and therefore the counts at the 400' height were not always accurate when compared to 'true' burrow counts obtained by ground staff. One of the two staff members had a particularly difficult time accurately counting prairie dog burrows from 400', yet the other staff member had similar results to burrow counts (mosaics) at 100' and 150' (**Table 3 & 5**). There was no attempt to count individual prairie dogs from 400' altitude. Although both technicians generally required the same amount of time to count/analyze imagery, future analyses using multiple staff members may require more training or first calibrating their staff against each other to ensure consistent and accurate counts.

Prairie dog densities in Boulder in 2021 tended to be lower, and actually half the densities, relative to those of the Fort Collins+Denver sites measured in 2020. Specifically, Boulder sites (from this study) had mean (SE) prairie dog densities of 14.4 ± 2.4 indiv/ha and prairie dog burrows of 161.0 ± 21.2 burrows/ha, whereas the seven sites of Fort Collins+Denver measured in 2020 had mean (SE) prairie dog densities of 32.4 ± 4.9 indiv/ha and prairie dog burrows of 171.1 ± 27.2 burrows/ha. The same methodologies and sampling were used in 2020 as in 2021. It is unknown whether the differences in prairie dog densities is due to site differences between Boulder and Fort Collins+Denver or annual variability. One difficulty that we have uncovered in our two years of prairie dog surveys in Colorado's Front Range is that accurate abundance estimates of prairie dogs (i.e., Minimum Numbers Known Alive; MKA) requires repeated measures to account for individuals above and below ground. While we are easily able to conduct such repeated measurements using ground-based surveys, drone flights and recordings only occurred once per colony because of the large time investment for flight and imagery transfer that preceded technician analysis. Additionally, the flights did not provide an 'instant image', as most flights took about 30 minutes and prairied dogs could move above and below ground during this extended period. To get accurate estimates of prairie dog 'true abundances', like MKA, the colonies should be flown multiple times across the day (and perhaps multiple days). Unfortunately, with current technology and very long processing time for just one flight covering a colony, the proposition to fly multiple times would be onerous and even less efficient than the single flights that we conducted. We hope that future technology will provide real-time analysis of the drone imagery, and this would be possible with the right machine-learning platform. In such a scenario, the drone's mission would be to fly, detect, count, and record each prairie dog (or burrow) quickly from altitudes ≥100'—there would be no need for any processing by humans/staff. Until such technology is available and tested, the labor requirement of using drones for burrow and prairie dog counts is far more time consuming than having field staff conduct the traditional on-the-ground counts.

Conclusions

We determined that 100' altitude mosaics produced using DGI drone were most accurate (closest to true, ground-based counts) for burrow abundance and generally so for prairie dog abundances. Our recommendation at this time is that the DGI drone flown at 100' altitude will most accurately reflect the true on-the-ground counts of prairie dog burrows and probably prairie dog abundances. Late summer flights are recommended over Spring or early summer flights because vegetation is most sparse in late summer. Video vs. mosaic had similar accuracy in some prairie dog counts, and 150' video was more accurate than 100' video as the greater field of view at 150' allowed the observer to detect stationary and moving prairie dogs more easily. Our evaluation uncovered differences among staff members in their accuracy of counting prairie dog burrows (and in some cases individuals) from drone imagery. Therefore, future projects may want to first calibrate their staff against each other to ensure consistent and accurate counts that can be repeatable. The time investment for using drones is perhaps the biggest staff and financial commitment. The DGI drone is ~$10,000 with the optics and all the batteries used in our study. Although the software we used was free, the image collection from drone, the significant duration to download and prepare the imagery for analysis, and the image processing/analysis time (actual prairie dog counting) should not be underestimated. Burrow counts using drone imagery took the longest of all imagery, generally 2-3 longer, as it averaged 8.1 hours of staff counting burrows on the already downloaded image. For prairie dog individuals, videos could be evaluated slightly faster than mosaics (average of 3.8 hours vs. 5.5 hours per imagery). Ground-based counts of prairie dogs or their burrows is far less time-consuming than making such counts using drones, and the rate difference was 3-4 times longer per hectare for drone-based counts than ground-based counts. Until technology improves and target colonies are very large (>2 km^2) or inaccessible, drone surveys are unlikely to be a more efficient technique than ground-based surveys for evaluating prairie dog abundances.

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Table 1. Site locations, area surveyed, dates flown in 2021, and altitude flown to survey prairie dogs using two types of small copter drones in Boulder, Colorado.

Site	Area surveyed (ha)	Dates flown	Altitudes flown (feet)
Johnson North	2.89	July 13	100, 150, 400
Gilbert North	3.84	August 4-5	100, 150, 400
Gilbert South	2.42	August 5 & 9 & 16	100, 150, 400
Waldorf	3.77	June 16-17 & August 12	100, 150, 400

Table 2. Prairie dog counts conducted in 2021 by each of two staff members upon analysis of drone imagery (video and mosaic) at four sites in Boulder, Colorado. All imagery except “Autel” was collected using a DGI drone. Waldorf was surveyed twice, when vegetation cover was very high (June) and when vegetation cover was low (August); the three other sites were surveyed in mid-July (Johnson North) and August (see Table 1 for exact dates). The “Max on-the-ground” represent the best estimate of minimum number known alive at each site based on multiple ground-based counts of prairie dogs using binoculars (see methods).

Staff Member 1:

Site	100’ video	150’ video	100’ Autel	150’ mosaic	100’ mosaic	Max on-the-ground
Johnson North	44	36	28	47	26	30
Gilbert North	25	32	64	50	58	67
Gilbert South	5	8	14	9	9	25
Waldorf (Aug)	81	63	59	83	54	73
Waldorf (June)	89	45	68	56	77	86

Staff Member 2:

Site	100’ video	150’ video	100’ Autel	150’ mosaic	100’ mosaic	Max on-the-ground
Johnson North	49	40	18	39	32	30
Gilbert North	23	35	92	60	45	67
Gilbert South	3	7	14	10	7	25
Waldorf (Aug)	67	48	49	34	48	73
Waldorf (June)	81	31	94	27	79	86

Table 3. Prairie dog burrow counts conducted in 2021 by each of two staff members upon analysis of drone imagery (mosaics mended from still pictures using Drone2Map software) at four sites in Boulder, Colorado. All imagery except "Autel" was collected using a DGI drone. Waldorf was surveyed twice, when vegetation cover was very high (June) and when vegetation cover was low (August) (see Table 1 for exact dates of each site). The "Max on-the-ground" represent the true counts of prairie dog burrows (active and potentially inactive) at each site based on ground-based counts.

Staff Member 1:

Site	100' Autel	400' mosaic	150' mosaic	100' mosaic	Max on-the-ground
Johnson North	375	348	311	402	507
Gilbert North	506	525	437	509	512
Gilbert South	364	388	434	357	293
Waldorf (Aug)	661	856	793	766	808
Waldorf (June)	516	598	473	612	693

Staff Member 2:

Site	100' Autel	400' mosaic	150' mosaic	100' mosaic	Max on-the-ground
Johnson North	308	260	264	568	507
Gilbert North	904	1356	1074	595	512
Gilbert South	339	246	299	361	293
Waldorf (Aug)	689	670	1178	703	808
Waldorf (June)	481	197	858	658	693

Table 4. Differences in prairie dog counts collected from drone versus on-the-ground surveys in 2021 (i.e., drone count minus ground count). Prairie dog counts from drone imagery analysis (video and mosaic) occurred by each of two staff members at four sites in Boulder, Colorado. All imagery except "Autel" was collected using a DGI drone. Waldorf was surveyed twice, when vegetation cover was very high (June) and when vegetation cover was low (August) (see Table 1 for exact dates of each site). The on-the-ground counts are those shown in Table 2.

Staff Member 1:

Site	100' Video	150' video	100' Autel	150' mosaic	100' mosaic
Johnson North	14	6	-2	17	-4
Gilbert North	-42	-35	-3	-17	-9
Gilbert South	-20	-17	-11	-16	-16
Waldorf (Aug)	8	-10	-14	10	-19
Waldorf (June)	3	-41	-18	-30	-9

Staff Member 2:

Site	100' Video	150' video	100' Autel	150' mosaic	100' mosaic
Johnson North	19	10	-12	9	2
Gilbert North	-44	-32	25	-7	-22
Gilbert South	-22	-18	-11	-15	-18
Waldorf (Aug)	-6	-25	-24	-39	-25
Waldorf (June)	-5	-55	8	-59	-7

Table 5. Differences in prairie dog burrow counts collected from drone versus on-the-ground surveys in 2021 (i.e., drone count minus ground count). Prairie dog counts from drone imagery analysis (mosaics mended from still pictures using Drone2Map software) at four sites in Boulder, Colorado. All imagery except "Autel" was collected using a DGI drone. Waldorf was surveyed twice, when vegetation cover was very high (June) and when vegetation cover was low (August) (see Table 1 for exact dates of each site). The on-the-ground counts are those shown in Table 3.

Staff Member 1:

Site	100' Autel	400' mosaic	150' mosaic	100' mosaic
Johnson North	-132	-159	-196	-105
Gilbert North	-6	13	-75	-3
Gilbert South	71	95	141	64
Waldorf (Aug)	-147	48	-15	-42
Waldorf (June)	-177	-95	-220	-81

Staff Member 2:

Site	100' Autel	400' mosaic	150' mosaic	100' mosaic
Johnson North	-199	-247	-261	61
Gilbert North	392	844	562	-3
Gilbert South	46	-47	6	68
Waldorf (Aug)	-119	-138	370	-105
Waldorf (June)	-212	-496	165	-35

Table 6. Time (in hours) required to count prairie dogs recorded in drone imagery. Prairie dog counts from drone imagery analysis (video and mosaics) were conducted by each of two staff members for the four study sites in Boulder, Colorado. All imagery except "Autel" was collected using a DGI drone. For further comparison, ground-based surveys take <10 minutes each and multiple were conducted in a day (see Methods).

Staff Member 1:

Site	100' Video	150' video	100' Autel	150' mosaic	100' mosaic
Johnson North	3.5	2.5	3	3	4
Gilbert North	4.5	4	5	5	6
Gilbert South	2.5	2	2	3	3
Waldorf (Aug)	4.5	4	4.5	4	4.5

Staff Member 2:

Site	100' Video	150' video	100' Autel	150' mosaic	100' mosaic
Johnson North	4	3	6	6.5	6
Gilbert North	5	4	11	9	10.5
Gilbert South	3.5	3	5.5	4	4
Waldorf (Aug)	6	5	8.5	7	7

Table 7. Time (in hours) required to count prairie dog burrows recorded in drone imagery. Prairie dog burrow counts from drone imagery analysis (mosaics mended from still pictures using Drone2Map software) were conducted by each of two staff members for the four study sites in Boulder, Colorado. All imagery except "Autel" was collected using a DGI drone. The "Max on-the-ground" represent the time it took to conduct on-the-ground counts of prairie dog burrows (active and potentially inactive).

Staff Member 1:

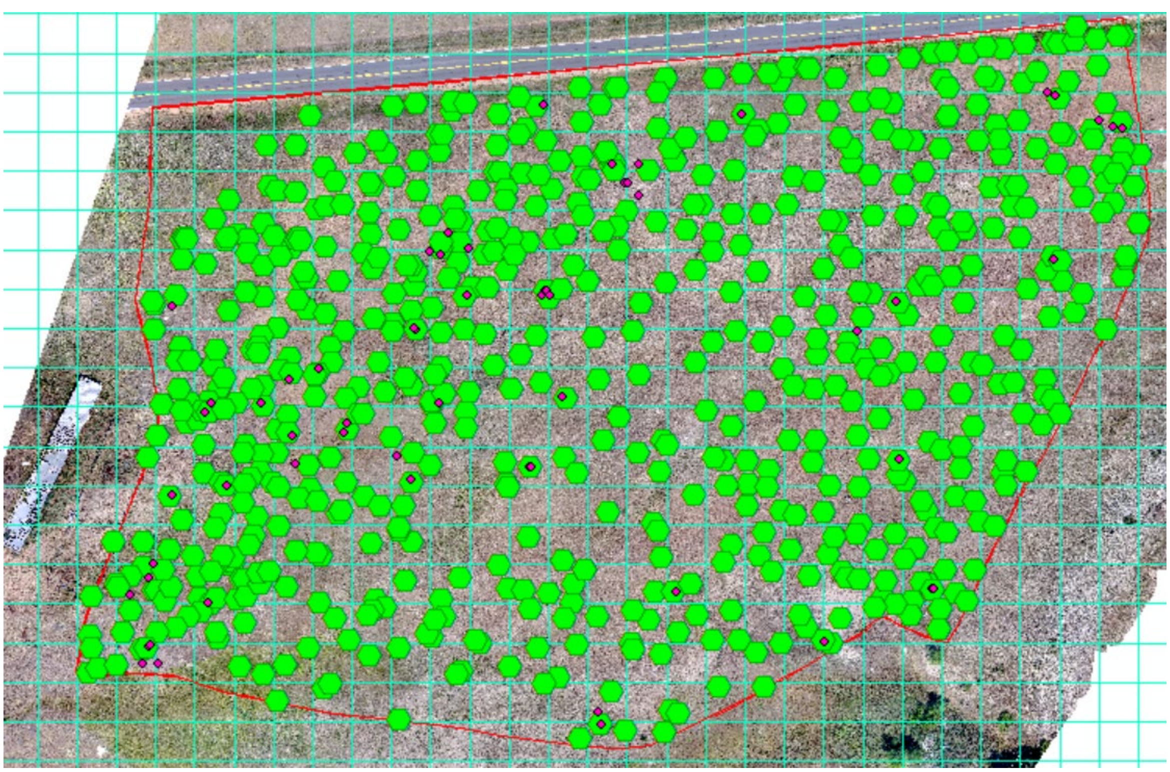
Site	100' Autel	400' mosaic	150' Mosaic	100' mosaic	Max on-the-ground
Johnson North	7	8	8	8	3.5 with 2 people
Gilbert North	12	8	10	13	2.5 with 2 people
Gilbert South	7	6	6	7	1 with 2 people
Waldorf (Aug)	9	8	9	9	2 with 2 people

Staff Member 2:

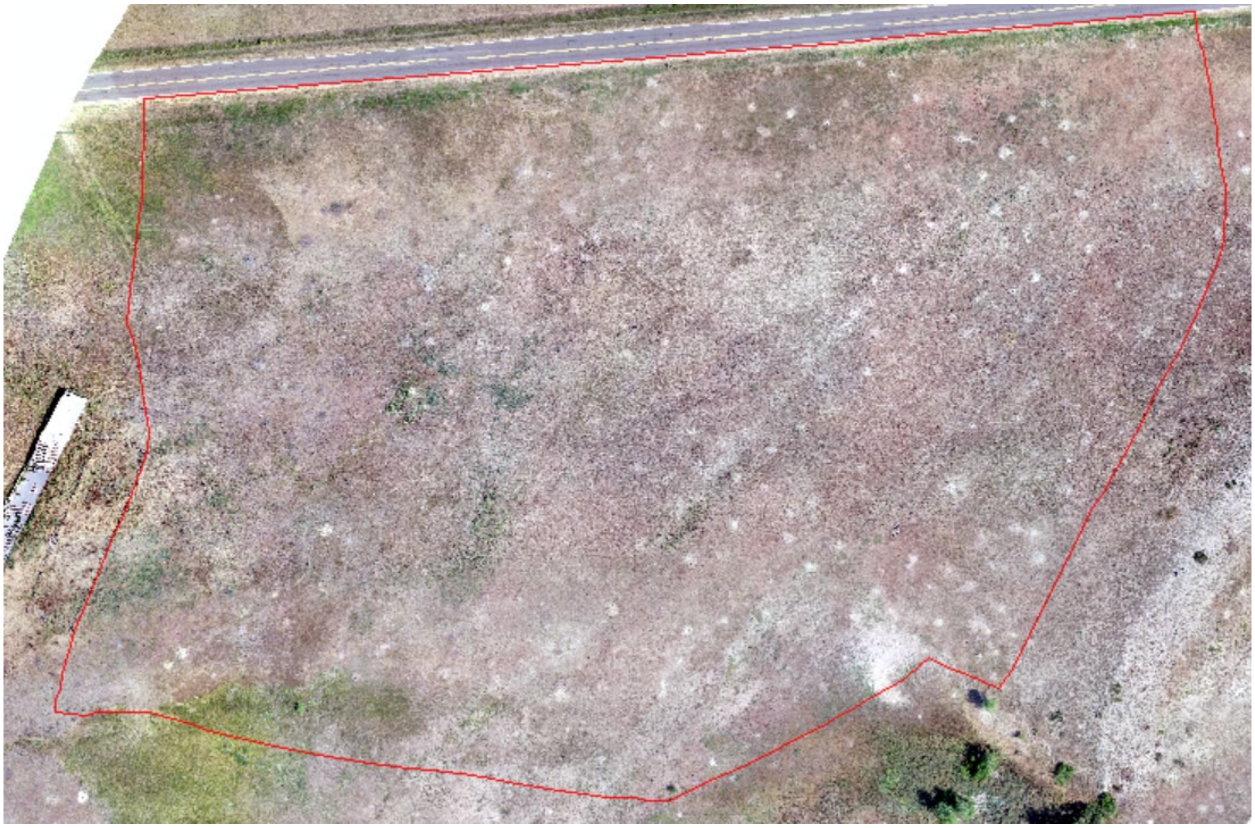
Site	100' Autel	400' mosaic	150' mosaic	100' mosaic	Max on-the-ground
Johnson North	8	8	8	9	3.5 with 2 people
Gilbert North	11.5	8	9	10.5	2.5 with 2 people
Gilbert South	6	3	4	7	1 with 2 people
Waldorf (Aug)	8	7.5	7.5	7.5	2 with 2 people

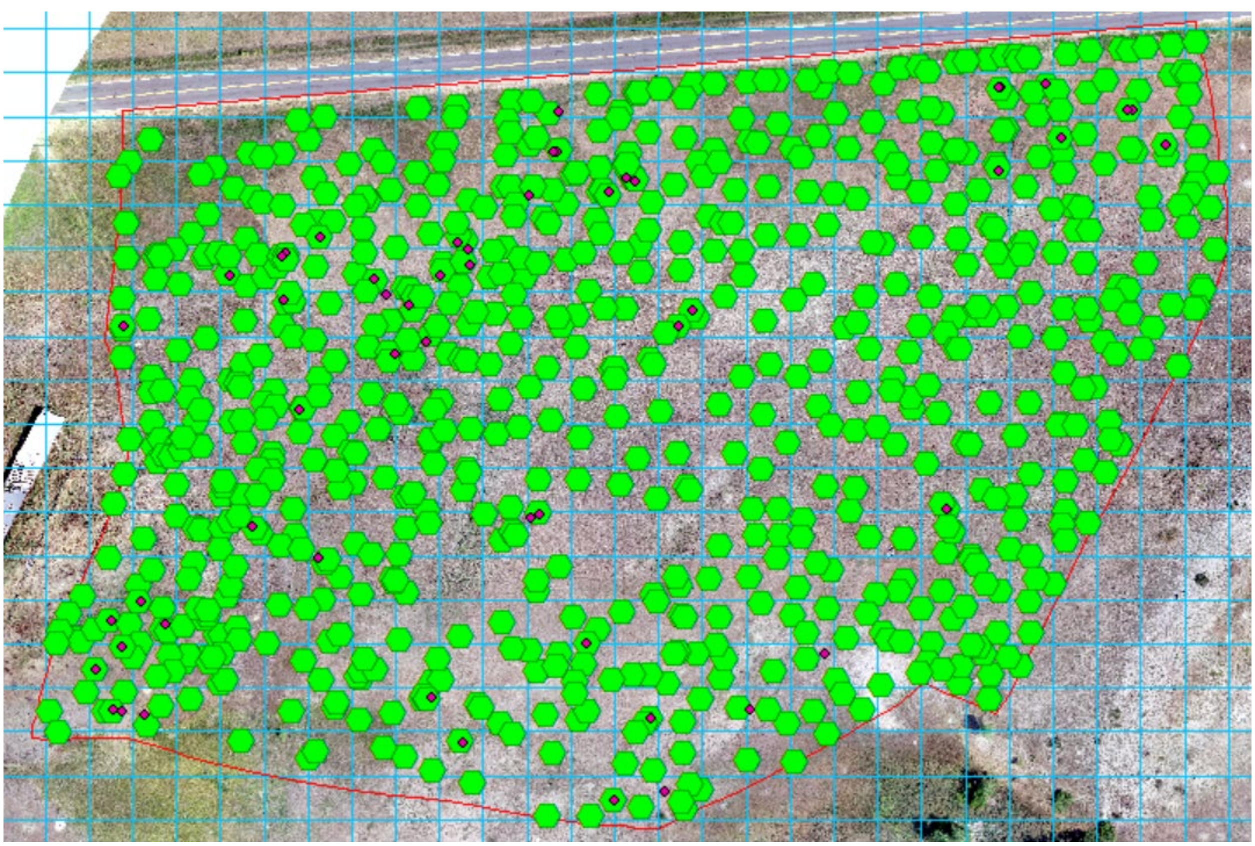
Appendix 1: Drone imagery with still pictured stitched into a mosaic

100ft Autel Evo, Waldorf (T2). Green hexagon = prairie dog mound; Pink diamond = prairie dog

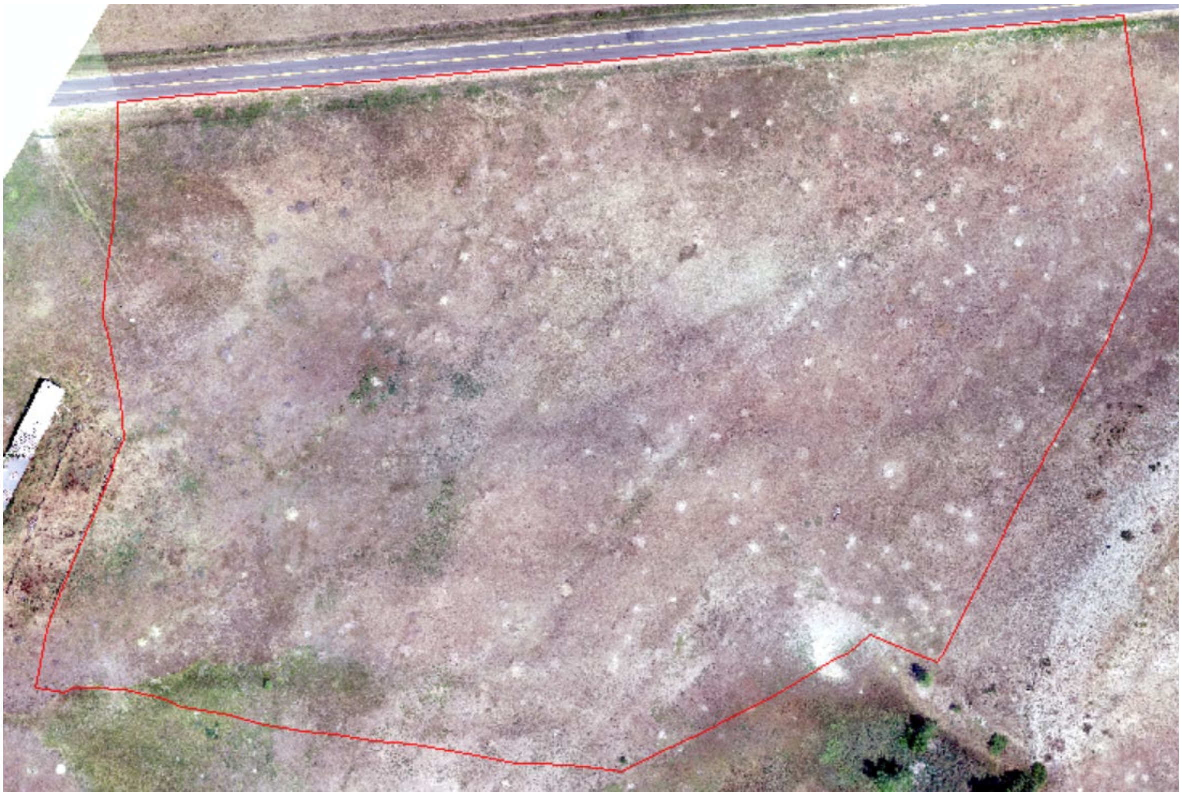


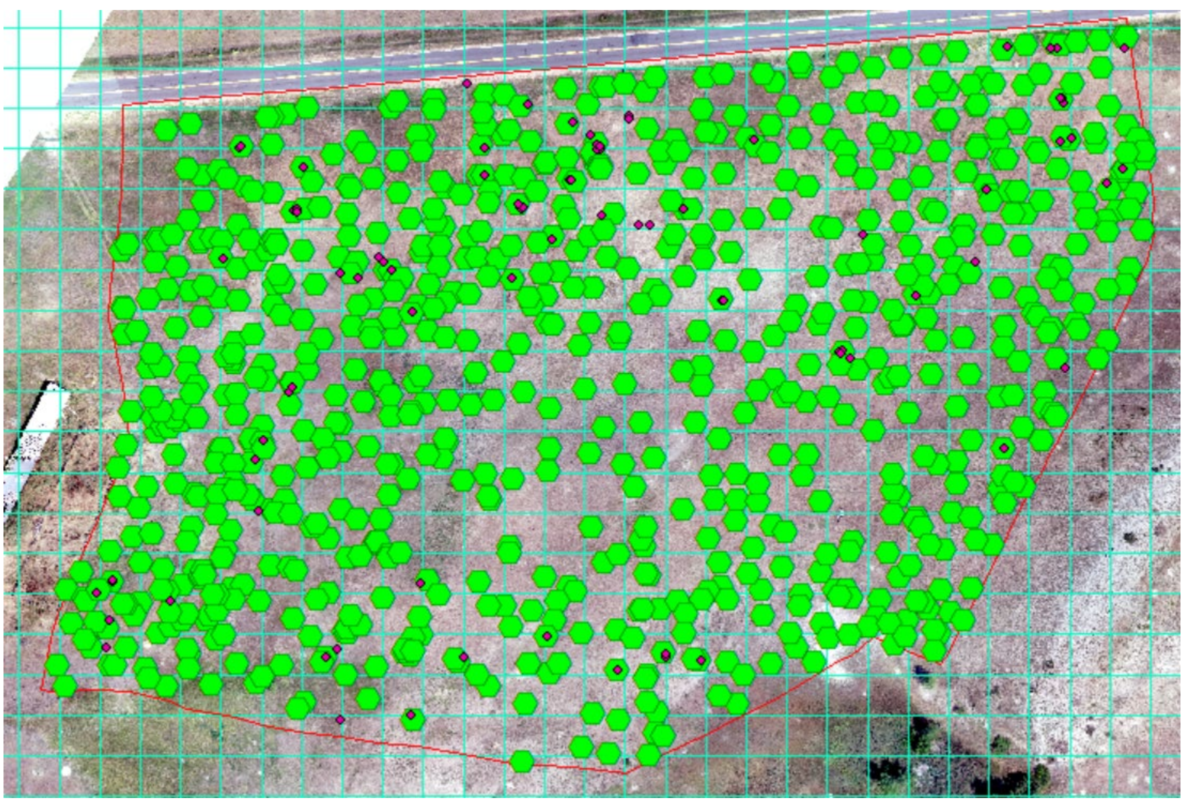
100ft DGI M210



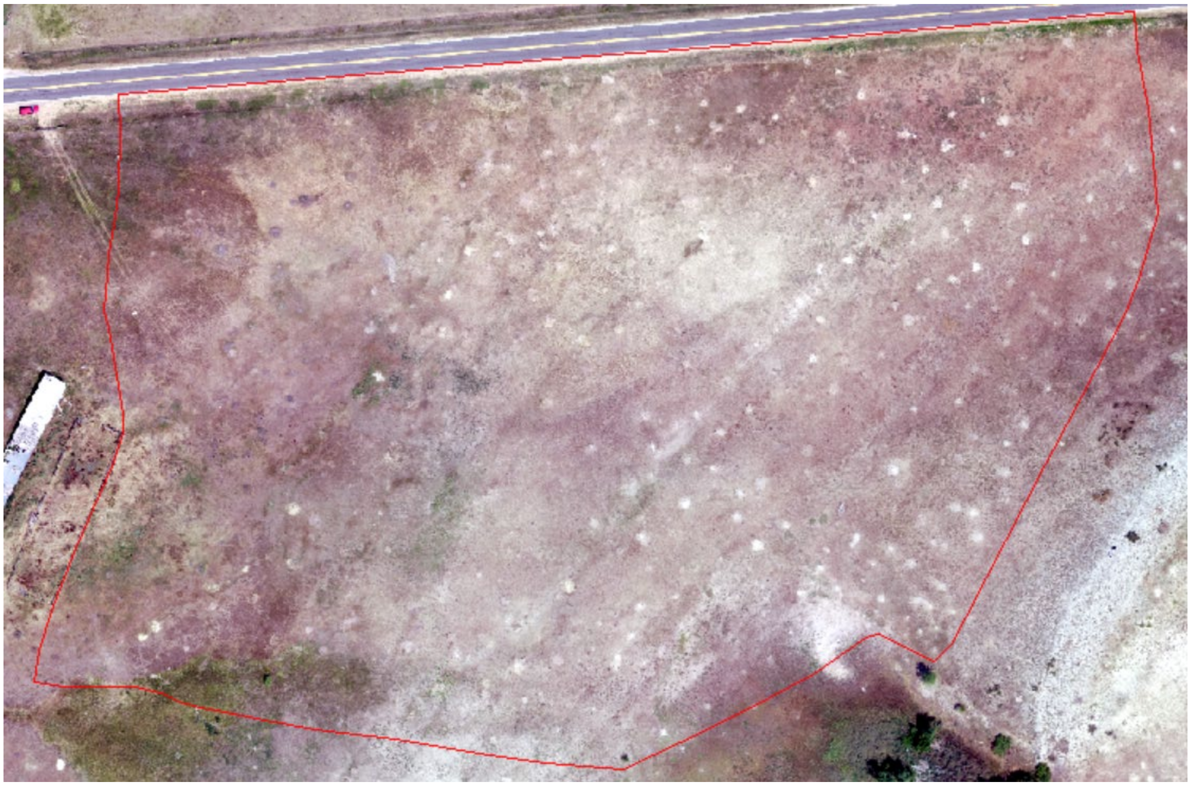


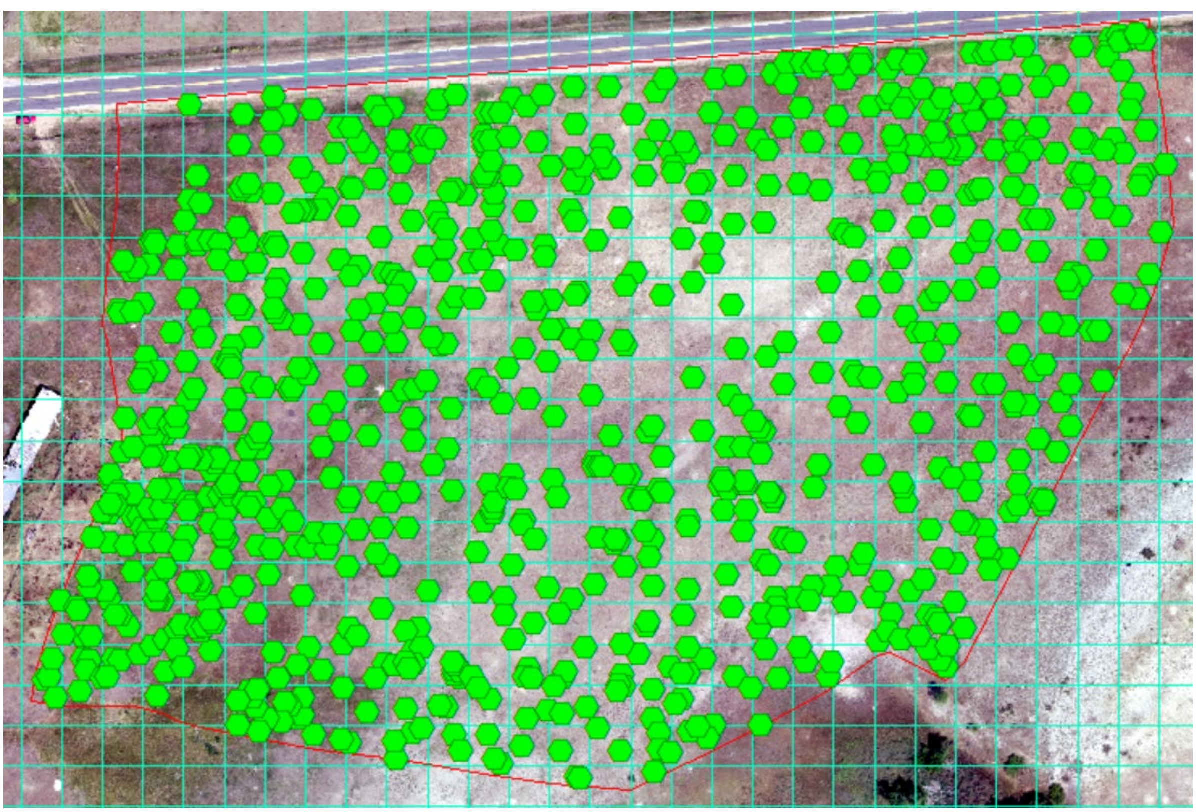
150ft DGI M210





400ft DGI M210





Waldorf 100ft DGI M210– prairie dog close-up. Note this was generally the level of resolution when staff analyzing the imagery would "zoom-in" to identify and distinguish prairie dogs and burrows.

Appendix 2 is a powerpoint file: 'Shiels_drone footage video clips 100 and 150', attached separately.

Appendix 3. Correlation figure showing the relationship between prairie dog density and burrow density when 11 sites were included (4 in Boulder, 2 in Denver, 5 in Fort Collins). The linear relationship was statistically significant (*P* = 0.02358).