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Improving Efficiency of Prairie Dog Surveys by Using a Small Copter Drone

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ABSTRACT: Prairie dogs are an accessible and enjoyed wildlife species in Colorado that require occasional surveys because populations can change abruptly due to plague outbreaks or human-induced control. We evaluated the use of small copter drones at four prairie dog colonies on Open Space and Mountain Parks lands, City of Boulder, to determine if this methodology improves efficiency over ground-based survey methods. We counted prairie dogs and burrows using two types of drones (DJI Matric 210 and Autel Evo II) at altitudes 100', 150', and 400' (burrows only). We recorded video and merged still images into orthomosaics 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 DJI Matric 210 drone were most accurate (closest to true, ground-based counts) for burrow abundance. We were not able to identify the best drone and altitude combination for drone-based prairie dog abundance. Overall video and mosaics both had similar accuracy in most prairie dog counts, however 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 and analyze imagery; videos could be evaluated slightly faster than mosaics (average of 3.8 hours vs. 5.5 hours per imagery) when counting prairie dogs, 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 drone technology improves to allow targeting larger colonies (>2 km^2) and automated detection and counting of wildlife become more commonplace, drone surveys are unlikely to be a more efficient technique than ground-based surveys for evaluating prairie dog abundances.

KEY WORDS: black-tailed prairie dogs, burrow density, *Cynomys ludovicianus*, drone survey, ground-based surveys, Unmanned Aircraft Systems, wildlife damage management

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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 recreationalists commonly visit (Hoogland 2002). All five prairie dog species, including the black-tailed prairie dog (*C. 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).

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 by which prairie dog populations can be surveyed is important for land managers. Traditional survey methods (e.g., binoculars, live-trapping) can be labor intensive and biased in detection rate, and can capture 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 (i.e., 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, Wang et al. 2019, Elmore et al. 2021), including counting burrows of prairie dogs in Colorado (Hasan 2019). 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 (JWF) 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 prairie dog pilot study the year preceding our study in Fort Collins, Colorado). To make our assessment as efficient and informative as possible to land managers considering using drones for prairie dog surveys, we did 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 noted our flight speeds, front and side overlap between images, time of day, and viable camera types (e.g., preferred zoom, and picture mosaic vs. video). Given these flight characteristics, we determined whether we could distinguish prairie dogs using the drone imagery, whether burrow density could predict prairie dog abundance, and the human hours or economic costs associated with such surveys. This information will help guide land mangers that are considering 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 anticipated that our findings will receive widespread interest as a modern survey method available for landowners and managers in 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 County, Colorado, and these sites were chosen after consultation with OSMP staff (particularly Victoria Poulton). The four sites were a subsample from those of OSMP (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 drones.

Drone Methodology and Prairie Dog Imagery for Density Estimates

We used our 2020 Fort Collins prairie dog colony findings of altitude, flight speeds, and best times of day to fly to guide our 2021 flights on OSMP lands. These included appropriate drone height (100-150', as heights lower than 100' would disturb prairie dogs), flight speed (4-12 mph), and transect width with a -45° camera angle (63' wide at 150' altitude; 38' wide at 100' altitude during video recording; we also programmed missions with 65-70% side and 80% front overlap to capture photos that would make up the orthomosaic). As long as wind speeds were low (e.g., sustained winds <20 mph), we flew during 08:45-15:00. 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 included: raising to hindlegs, distinct (alarm) vocalizations, retreat to burrow entrance, and retreat underground in burrow. If significant disturbance to prairie dogs had occurred from the drone flying overhead, which was 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 higher 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 or distances between transects differed due to multiple camera focal lengths. All 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 30 m outside of the survey area; thus, the drone reached the 100' minimum flight altitude >30 m distance 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 (Autel Robotics, Shenzhen, China), fixed with a Sony IMX586 camera (48MP), and 2) DJI Matric 210 (DJI; Shenzhen, China), 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 Evo II with camera is ~$1,500 whereas DJI Matric 210 with both cameras approximately $15,000 with the listed cameras and batteries.

After choosing the drone and appropriate altitude, speed, and transect width, an autonomous flight plan for each site was developed and programmed using mobile mapping software. Based on previous drone flights at the anticipated flight speeds (4-6 mph with DJI Matric 210) and altitudes, battery changes were required approximately every 25-30 minutes. Once the drone 'returns home' to land, batteries were switched out, and the drone

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

was 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. Once the drone imagery had been captured, there were two readily available software programs that were used in our analysis: ArcMap (ESRI, Redlands, CA), and Drone2Map (ESRI, Redlands, CA). The Drone2Map software stitched the photos together, using many points of reference from overlapping images to create a single image that we call an orthomosaic. Personnel at USDA were then able to count prairie dogs and burrows (active and inactive) from the mosaic using Arcmap. We used the DJI Matric 210 drone to capture video with a zoom factor of 4×. After all transects were flown and we ensured adequate coverage of the site by viewing the real-time recording in the field via a laptop, USDA personnel transferred imagery to USDA servers and counted prairie dogs and burrows from their offices. Double counting prairie 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, cameras, altitude, flight speeds, width of transects, 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 the drone and camera that was the 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 site (see Severson and Plumb 1998). Prairie dog counts were then performed from 30 m outside each site 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 resumed (~15 min). To count the animals, sites were scanned with binoculars starting at one end 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. Multiple counts were 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 >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. 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 (Figure 1). Although the accuracy of the drone-based counts and ground-based counts varied among sites (Tables 2-3), 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 (Tables 2-3), 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 some mosaics was reported to be 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 our remaining observations thus occurred in late summer (mid-July-August).

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. We completed 400' flights with Autel Evo II but the imagery was so poor (blurry) that ground/rocks could not be distinguished from prairie dogs; none of the 400' flights with Autel Evo II 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). 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 DJI Matric 210 drone were most accurate (closest to true, ground-based counts) for burrow abundance (Table 3) but there was not a clear winner for drone × altitude for prairie dog abundances (Table 2).

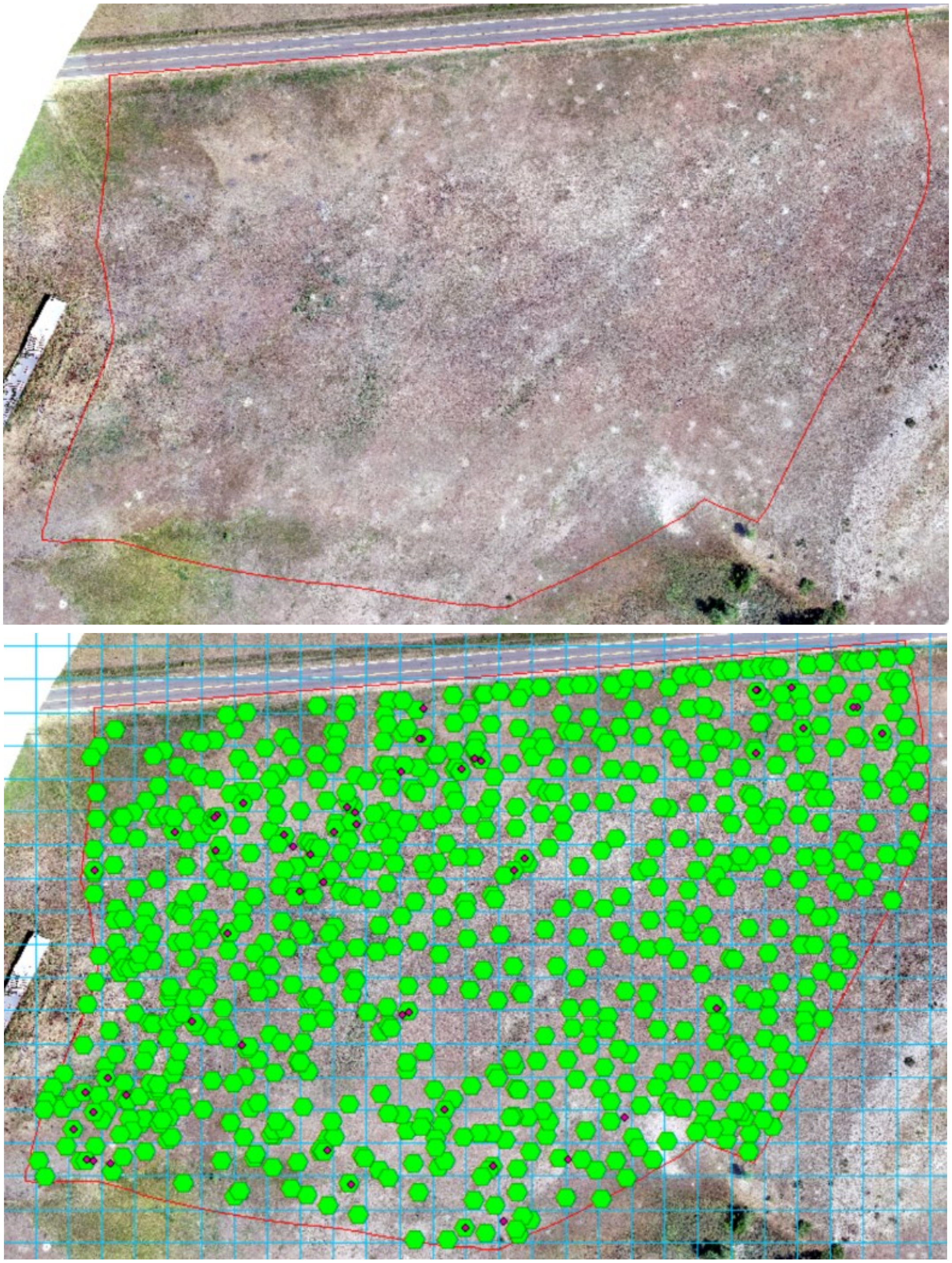

Figure 1. 100' drone imagery from Waldorf site. The upper image was created by stitching together 620 still images taken by the drone in flight to make the single mosaic pictured. The lower image shows the locations that analytical staff identified prairie dog individuals (small diamonds) and burrows (larger green dots) by using the upper image and zooming in.

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. There did not appear to be a correlation between burrow density and prairie dog density.

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

Table 2. Prairie dog counts conducted in 2021 by two staff members upon analysis of drone imagery (video and mosaic) at four sites in the City of Boulder, Colorado. All imagery except "Autel" was collected using a DJI Matric 210 drone. Waldorf was surveyed twice, when vegetation cover was very tall (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).

Site	100' video	150' video	100' Autel mosaic	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

Table 3. Prairie dog burrow counts conducted in 2021 by each of two staff members upon analysis of drone imagery (orthomosaics using Drone2Map software) at four sites in Boulder, Colorado. All imagery except "Autel" was collected using a DJI Matric 210 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 mosaic	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 mosaic	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

in Google Earth and aid in on-ground counts, which took 1 hour/site with 2 people. However, the bulk of the field collection efforts were the drone flights and on-ground counts.

2) Imagery Download: whereas video is a single file, the mosaics are formed by stitching all the still images together using Drone2Map software (Figure 1). A standard computer (as used in this study) required 12+ hours to make an orthomosaic 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) Imagery Analysis: 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. Both staff members required about the same amount of time to perform counts by analyzing imagery. The labor requirement of using drones for burrow and prairie dog counts is more time consuming (4.9-5.4 hours/ha for prairie dog counts, and 6.2 hours/ha for burrow counts; Figure 1) 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 are 0.6-2.2 hours/ha). In short, it took 3-4 times as

many hours to count prairie dogs or burrows using drones (field work+mosaic 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 survey for prairie dogs and burrows while conducting simultaneous ground-based counts has provided the unique 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 of prairie dog sites to 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 burrow entrances but not disappear below ground. 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 DJI 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. 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 Evo II drone was perceived as slightly riskier to prairie dogs than the DJI Matric 210 used during our study, perhaps because the Autel Evo II more closely resembles a raptor in flight or size.

The 100' altitude mosaics produced using the DJI Matric 210 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. Unfortunately, the 100' mosaics were the slowest to fly because of the high frequency of transects needed to achieve high image overlap, as the 100' altitude was the closest to the ground (i.e., narrowest field of view) relative to the other two altitudes flown. The hundreds of still pictures increased processing time needed to stitch the pictures together using various tie points (e.g., rocks, bushes, hills) to create the single mosaic. The greater the altitude, the wider the field of view and therefore fewer pictures needed to capture the entire prairie dog site. Fewer pictures also resulted in fewer drone stops during a programmed mission and in some cases no battery changes. A final advantage of creating orthomosaics and having staff place points representing prairie dogs and burrows on the GIS files is that it facilitates future spatial and temporal analysis of the target wildlife. Additionally, human analysis of the orthomosaics and videos can also be used to train artificial intelligence programs (i.e., machine learning) to more quickly identify and count prairie dogs and burrows from collected imagery.

Drone videos and mosaics 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. 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. 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.

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 little 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 traditional on-the-ground counts.

Recommendations

Our recommendation at this time is that the DJI Matric 210 drone flown at 100' altitude will most accurately reflect the true on-the-ground counts of prairie dog burrows. Late summer flights are recommended over spring or early summer flights because vegetation is most sparse in late summer. Videos and mosaics 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 DJI Matric drone is ~$15,000 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 time needed 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 analysis, generally 2-3 longer, as it averaged 8.1 hours of staff counting burrows on the already downloaded image. For counting individual prairie dogs, 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 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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