Estimates of Population Size of Gunnison's Prairie Dogs in the Aubrey Valley, Arizona Based on a New Monitoring Approach

Submitted to:

Mr. Jeff Pebworth
Wildlife Program Manager, Region III
Arizona Game & Fish Department
5325 North Stockton Hill Road
Kingman, Arizona 86401

Prepared by:

Aaron N. Facka
Robert C. Lonsinger
and
*Gary W. Roemer, Ph.D.

Department of Fish, Wildlife and Conservation Ecology
PO Box 30003
New Mexico State University
Las Cruces, NM 88003

* To whom correspondence should be addressed: groemer@nmsu.edu, (575)-646-3394

Introduction

Black-footed ferrets (*Mustela nigripes)* are an obligate predator of prairie dogs (*Cynomys* spp.), and depend on large prairie dog populations to exist (Henderson et al. 1969, Hillman and Linder 1973, Miller et al. 1996). The majority of black-footed ferret reintroduction and recovery efforts have occurred on black-tailed prairie dog (*C. ludovicianus)* colonies because this species lives in higher densities (> 10 prairie dogs/ha) relative to other prairie dogs (Hoogland 1995). Aubrey Valley, Arizona is the only site where ferrets were reintroduced into colonies of Gunnison's prairie dogs (*C. gunnisoni*); ferrets were reintroduced there in 1996 (Winstead et al. 1998**).**

Currently, management of ferrets in the Aubrey Valley relies on an assessment of the relative abundance of prairie dogs that is based on the number of active prairie dog burrows (King et al. 2005). The estimation and mapping of the density of active burrows, and the assumption that higher densities of burrows equates to greater prairie dog and ferret density is a major tenet of management in the Aubrey Valley (King et al. 2005). Areas where there is a high density of prairie dog burrows are targeted for both the release and monitoring of ferrets because it is believed they use these areas preferentially. There are no published studies, however, that correlate the density of prairie dog burrows with the density of ferrets, nor have any studies established a clear link between the density of burrows and the abundance of Gunnion's prairie dogs.

Estimation of prairie dog abundance based on the density of burrows has been proffered as an effective means of evaluating potential ferret habitat for both black-tailed and white-tailed (*C. leucurus)* prairie dogs (Biggins et al. 1993, Winstead et al. 1998, King et al. 2005), yet several studies have demonstrated that counts of active burrows are unrelated to population density of prairie dogs (Menkens et al. 1988, Powell et al. 1994, Severson and Plumb 1998, Biggins et al. 2006). Consequently, counting burrows in the Aubrey Valley may be an inaccurate index of prairie dog density and its exclusive use in designing sampling surveys for released ferrets also may lead to inaccurate assessments of the spatial distribution and abundance of ferrets. In order for counts of active burrows to be a useful index of prairie dog abundance or density, they should be corroborated with more robust estimates of population size.

Several other methods have been applied to estimate the abundance of prairie dogs. Maximum above ground counts (MAGC) have been used as a more reliable estimate of population size (Powell et al. 1994, Severson and Plumb 1998), but at least one study revealed that MAGC, though correlated with population size, is biased low (Facka et al. 2008). Abundance of prairie dogs has been estimated with more stringent methods such as mark-recapture or complete enumeration (Knowles 1985, Menkens and Anderson 1993, Hoogland 1995, Severson and Plumb 1998). Though complete enumeration is an effective and accurate means to estimate population size it requires an extensive time commitment, which limits its utility (Hoogland 1995). Severson and Plumb (1998) estimated densities of black-tailed prairie dogs using a mark-recapture approach while at the same time recording MAGC, and then used a regression model to estimate population size from MAGC alone. Facka et al. (2008) found that MAGC, population estimates using mark-recapture, and derived regression models are all biased low and that estimates made with mark-resight methods were superior to all other approaches for estimating the abundance of prairie dogs.

In this study we estimated prairie dog population size and density using MAGC, mark-recapture and mark-resight approaches on 12 colonies of Gunnison's prairie dogs and compared these population estimates to counts of active burrows.

Methods

Study site

This study was conducted in the Aubrey Valley Experimental Population Area (AVEPA), a 220 km^2 area located approximately 12 miles west of the town of Seligman, in northern Arizona. In 1996, in cooperation with the U.S. Fish and Wildlife Service, Navajo and Hualapai Nations, the Arizona State Land Department, and The Phoenix Zoo, the Arizona Game & Fish Department selected Aubrey Valley as a black-footed ferret reintroduction site. The Aubrey Valley is currently the only black-footed ferret reintroduction site in the southwestern United States and the only site where ferrets have been reintroduced into Gunnison's prairie dog colonies.

Annual precipitation in the valley averages 25 to 30 cm, the dominant vegetation is blue grama (*Bouteloua gracilis),* mixed with Galleta grass (*Hilaria jamesii*), Indian rice grass (*Oryzopsis hymennoides),* creosote bush (*Larrea tridentate),* yucca (*Yucca elata*), and cholla cactus (*Opuntia acanthocarpa)* (Brown 1982, King et al. 2005). The Aubrey Valley is surrounded by ridges dominated by pinyon-juniper (King et al. 2005).

Both state and tribal lands within the AVEPA are leased to the Cholla Cattle Company. Part of the valley grazed by cattle is under the operation of the Big Boquillas Ranch.

Prairie dog survey methods

Twelve plots were selected throughout the Aubrey Valley on which to sample populations of prairie dog. These plots were distributed based on the number of prairie dog burrows per hectare as follows: Four in areas of high burrow density (>100 active burrows/ha), four in areas of medium burrow density (51-100 active burrows/ha), and four in areas of low burrow density ($\leq$ 50 active burrows/ha). Plots were selected by visually evaluating sightability (vegetation and topography), then verifying the presence of prairie dogs based on visual and audible cues, and using known burrow densities from the summer of 2005 (King et al. unpub. data). Each plot was 4 hectares, measuring 200 meters by 200 meters square.

Six of the twelve plots (2 within each range of density of burrows) were randomly selected and sampled exclusively with the Maximum Above Ground Count (MAGC) method. The remaining six plots were sampled using Mark-Recapture and Mark-Resight techniques.

Maximum above ground counts (MAGC)

An attempt was made to sample each of the six MAGC plots once per month, beginning in March following the emergence of prairie dogs from hibernation, and continuing until the dogs entered hibernation in the following fall/winter season. Maximum aboveground counts of prairie dogs on each of these plots were conducted for each of 3 consecutive sessions, once per month. Sessions were between 7:00-10:00 hrs and 17:00 – 20:00 hrs, to minimize problems associated with heat mirage, and to maximize the number of animals that were aboveground. Three locations (all located approximately 100 meters from the edge of the plot) were selected from which to observe prairie dogs. Each month, the survey location was randomly selected. Counts of prairie dogs were conducted from atop a 13-ft tripod chair using a 20-60x variable power spotting scope mounted on an adjustable tripod.

After arriving at an observation site, an observer would wait quietly for 20 minutes to allow the prairie dogs to acclimate to their presence. Scans began and ended at predetermined points located slightly off the sampling area to ensure that the entire area was sampled and that there was a high probability of seeing all animals. Plots were marked out into smaller subsections with T-posts to facilitate sampling the area. Each plot was scanned once each 15 minutes until a MAGC occurred that was also followed by three subsequent declining counts. During each scan, both the number of adult and juvenile prairie dogs was recorded. Sessions were occasionally shortened or missed due to seasonal weather that prohibited surveys, including heavy rain and lightning.

Mark-recapture/mark-resight

Capture-recapture (mark-recapture) methods have been widely used on a variety of vertebrate species (including prairie dogs) to obtain estimates of demographic parameters including density and survival (Menkens and Anderson 1993; Pollock et al. 1990). Because estimates are based on recapturing individuals, the labor required may limit the number of areas studied or the intensity of study. Mark-resight has recently been employed as a method to estimate the abundance and density of black-tailed prairie dogs in southern New Mexico (Facka et al. 2008).

Six plots were sampled using mark-resight and mark-recapture techniques. Each plot was trapped two times. Trapping began in April, following the emergence of prairie dogs from hibernation, and again in late May to early June when pups were emerging, in an attempt to trap all pups at all sites.

Each site was trapped using approximately 250 traps. One trap was placed at the entrance to each burrow. If more burrows were present than traps available, traps were preferentially placed at burrows with recent prairie dog sign (e.g., fresh digging and/or fresh feces). Medium-size box traps baited with a mixture of sweet horse feed and dry oats were used to live-capture prairie dogs. Traps were wired open and pre-baited the day they were laid out, and were left undisturbed for 4 additional days prior to being set to acclimate the prairie dogs to the presence of the traps. Traps were then baited and set at dusk the fourth day. The combination of pre-baiting in conjunction with lack of morning disturbance has increased trap success of black-tailed prairie dogs (*C. ludovicianus*) from ~ 5% to 20% (G. Roemer, unpubl. data). Trapping occurred for 3 consecutive days on each plot.

All trapped individuals were weighed, sexed, aged, a tissue sample collected, and uniquely marked. Adult prairie dogs were uniquely marked using a subcutaneous passive integrated transponder (PIT) tag (AVID Inc.), while juveniles were marked using ear tags (#1005-1, National Tag and Band Co.). Both adult and juveniles were marked externally with a unique alphanumeric code using Nyanzol-D dye (Hoogland 1995). Nyanzol-D remains visible on prairie dogs until such time as they molt and was used to identify individuals during monthly sighting surveys. Each individual prairie dog was returned to its capture location following processing. After completion of the processing, all traps were rechecked before leaving the site to ensure no additional dogs had been caught.

Observations and counts of marked prairie dogs were conducted at each sampling site, for each of 3 consecutive sessions, once per month. The first sighting sessions occurred within the first 3 days following the end of the trapping session. As with MAGC, scans occurred between 7:00-10:00 hrs and 17:00-20:00 hrs and followed a similar sampling protocol.

Marked animals were identified based on their unique alphanumeric code with unmarked animals also counted. Animals that could not be distinguished as marked or unmarked (often prairie dogs sit in their burrows with only their heads exposed) after a period of two minutes were skipped and not counted in the scan.

Counts of active burrows per plot

The number of burrows on each 4 ha plot was counted, and each burrow was recorded as active or inactive, beginning in May after the emergence of prairie dog pups. A distinct burrow was defined as an opening of at least 7 cm of which the bottom could not be seen. Two openings within one meter of each other were counted as one burrow. Burrows were assessed following the same criteria described by Biggins et al (1993). Each burrow was determined to be active or inactive based on the presence of fresh prairie dog feces within the opening of the burrow or within 0.5 m of the center of the burrow entrance. Each burrow was marked with a flag and a GPS location was taken. This ensured that no burrows were missed and facilitated mapping the distribution of the burrows across each plot.

Population estimates

Estimates of prairie dog population size were made with four different approaches both prior to and following emergence of juveniles. At each colony and for both time periods we estimated the minimum number of animals known alive (MNKA) by adding the maximum number of unmarked animals observed over a series of scans to the total number of marked animals. In this way we attempted to establish a minimum population estimate for each population and discrete time period.

The maximum number of animals counted across all scans at a colony was taken to represent the MAGC. This method applied to all colonies sampled during the study. Both adults and juveniles were counted equally and were not analyzed separately.

Mark-recapture estimates of population size were made within program MARK using the “full closed captures with heterogeneity” data type (White and Burnham 1999). For each colony and time period, population estimates were made using the most appropriate of the eight mark-recapture models outlined by Otis et al. (1972). Akaike’s Information Criterion- corrected (AIC_c) was used to select the most appropriate closed-population model (Burnham and Anderson 1998); estimates of population size from the most well supported model were used.

Mark-resight estimates were made using Bowden’s estimator as implemented in program NOREMARK (White 1996). Bowden’s estimator was chosen because (1) it allows for individual heterogeneity in sighting probability, (2) it allows for sampling with replacement, which permits double counting of both marked and unmarked individuals, and (3) all animals may be used in the analysis even when they are not individually indentified, but only known to be marked (Bowden and Kufield 1995). Four estimates of population size made with mark-resight violated the closure assumption of the Bowden's estimator because scans were performed several weeks following the marking of animals. These scans were also conducted following the emergence of young, which can have high rates of mortality (Hoogland 2001). High rates of mortality over short periods of time may have caused a loss of marked animals within the population. Given the high potential for bias in this situation these estimates were removed from further analysis.

Analysis

Comparisons between population estimates

We compared population estimates from six colonies both prior to and after juvenile emergence (n = 12). A Pearson correlation coefficient was used to examine for a correlation among population estimates derived from different estimators.

Relationship between population estimates and density of burrows

We classified colonies based on the density of burrows (low, medium and high) and then compared estimates of population size across all methods using simple linear regression. Separate regression tests were performed for periods prior to and after juvenile emergence. The classification of density of burrows was used as the explanatory variable upon which population estimates, the response variable, were regressed. Tests for differences in mean population size based on the density of burrows were also performed using a larger data set where only the MAGC was estimated.

Correcting the MAGC using sighting probability

Sighting probability was defined as the proportion of marked animals observed relative to the total number of marked animals during a single scan. We believed *a priori* that sighting probability would vary both temporally (between seasons) and spatially (among colonies). Additionally, we hypothesized that there would be an interactive effect between colony and time because the composition and structure of vegetation varied among colonies and with season. Sighting probability was a proportion, so we assumed it followed a binomial distribution and transformed this variable with an arcsine transformation to ensure normality and homoscedasticity (Zar 1999). This allowed us to use more powerful parametric tests in a multi-factorial approach to assess differences in sighting probability.

Above ground counts represent only the observed proportion of the total number of animals actually present, whereas sighting probability is an estimate of that proportion. More individuals can be observed at colonies with high sighting probabilities, compared to colonies with low sighting probabilities, even if population sizes are equivalent. Consequently, sighting probability has an influence on the average and maximum number of animals counted during a scan. Sighting probability can bias counts to the point where the number of animals observed provides an inaccurate measure of relative abundance. We estimated an average sighting probability for each colony and time period ($n = 12$) using the mark-resight data and then applied this average sighting probability to the MAGC for that colony to derive a population estimate:

$$\hat{N} = \text{MAGC / sighting probability}$$

We then regressed these population estimates on our initial mark-resight estimates from the Bowden's estimator to evaluate the relationship between the two estimators.

Results

Comparison of population estimates

Estimates of population size varied considerably depending on the type of estimation method used (Table 1). Population estimates made with mark-resight were higher than all other methods. In contrast, mark-recapture produced estimates that were generally larger than the MAGC but were below the MNKA 75% (9 of 12) of the time (Table 1); thus, population estimates made with mark-recapture were biased low. The MAGC was consistently lower than the MNKA and was also below the total number of marked animals on 61% of sampling occasions (Table 1). Though "true" population sizes were unknown, only estimates made with mark-resight were consistently above the MNKA; which indicates that estimates made with other methods were negatively biased. Confidence around population estimates was also different between mark-resight and mark-recapture methods. Mark-resight had larger 95% confidence intervals (CI) relative to mark-recapture. As a percentage of their respective estimates however, mark-resight had CIs that were smaller (mean = 65%, SD = 34, n = 12) compared to mark-recapture (mean = 96%, SD = 167, n = 12). These relatively smaller confidence intervals indicated estimates made with mark-resight provide a higher level of precision.

Table 1: Estimates of population size through time at six sites, pre- and post-emergence of juveniles, of Gunnison's prairie dogs using the number of marked individuals (Marked), the Minimum Number of animals Known Alive (MNKA), uncorrected Maximum Above Ground Counts (MAGC), mark-recapture (Capture) and mark-resight (Resight) approaches.

Site	Time	Marked	MNKA	MAGC	Capture (95% CI)	Resight (95% CI)
HD1	Pre	26	30	12	28 (27 – 32)	37 (29 – 48)
	Post	61	79	29	92 (80-112)	128 (97-169)
HD2	Pre	20	33	15	21 (21 – 150)	50 (32 – 78)
	Post	61	85	39	72 (66 – 87)	125 (97 – 163)
MD1	Pre	31	56	37	37 (33 – 47)	59 (50 – 71)
	Post	47	65	35	67 (58 – 86)	79 (63 – 98)
MD2	Pre	21	30	8	21 (21 – 25)	81 (42 – 159)
	Post	26	45	31	41 (20 – 82)	64 (64 – 89)
LD1	Pre	28	38	10	33 (29 – 44)	77 (45 – 132)
	Post	67	86	45	110 (89 – 153)	116 (97 – 139)
LD2	Pre	13	39	26	13 (13 – 15)	96 (66 – 139)
	Post	29	74	59	55 (29 – 102)	105 (84 – 131)

Estimates of population size made with mark-resight were positively correlated with both the MNKA ($r = 0.80$, $p < 0.01$, $n = 12$) and with estimates made with mark-recapture ($r = 0.70$, $p = 0.01$, $n = 12$), but only marginally correlated with MAGC ($r = 0.54$, $p = 0.07$, $n = 12$). Estimates of population size made with mark-recapture were significantly correlated with both the MNKA ($r = 0.91$, $p < 0.01$, $n = 12$) and the MAGC ($r = 0.60$, $p = 0.04$, $n = 12$). In addition the MNKA and MAGC were positively correlated ($r = 0.79$, $p < 0.01$, $n = 12$). These positive correlations indicate that although there were differences (bias) among estimation methods, they all still reflected the same relative patterns of abundance across colonies and time (Table 1).

The density of prairie dogs estimated with mark-resight (calculated as the estimate of population size divided by 4.0 ha) averaged 16.66 ($SD = 5.46$, $n = 6$) prairie dogs/ha prior to juvenile emergence but increased to 25.70 (SD = 6.49, n = 6) following juvenile emergence (Figure 1). Concordant with their lower population estimates all other methods suggested much lower densities of prairie dogs prior to (range = 4.5 – 9.41 prairie dogs/ha) and after juvenile emergence (range = 9.17 – 18.20 prairie dogs/ ha; estimates for each colony can be derived from Table 1).

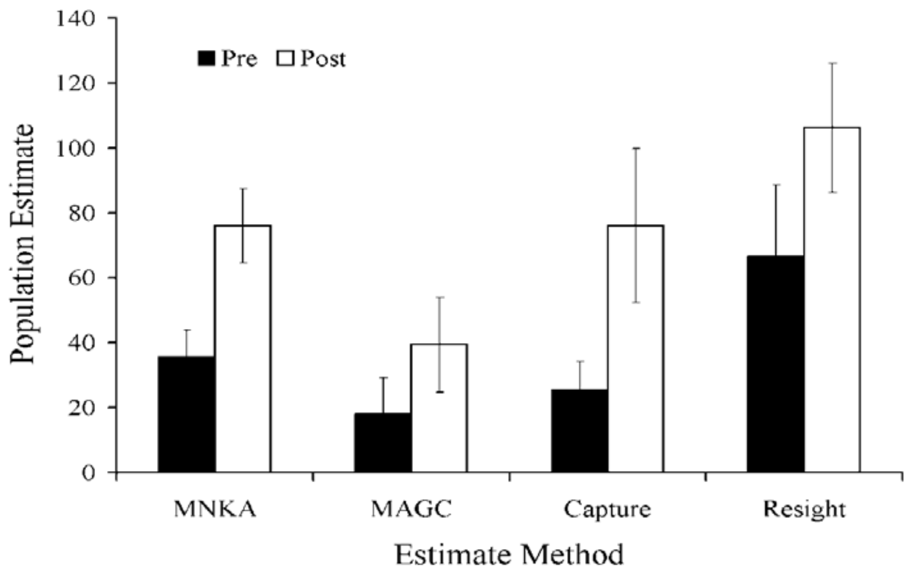

Figure 1: Average population estimate across colonies for four types of population estimates: the minimum number of animals known alive (MKNA), the maximum above ground count (MAGC), mark-recapture (Capture) and mark-resight (Resight) where error bars are equal to one standard deviation.

Prairie dog abundance and burrow density

Classification of colonies based on the density of active burrows had little relationship to any estimate of prairie dog abundance during the period prior to juvenile emergence (Figure 2a). Population estimates derived from mark-resight data did not differ among burrow classes ($F = 1.67$, d.f. = 1, 4, $p = 0.27$). A similar pattern occurred among population estimates made with mark-recapture, where there was no detectable relationship between the estimate of mean population size and the density of prairie dog burrows ($F = 0.22$, d.f. = 1, 4, $p = 0.66$). There also was no statistical difference in prairie dog abundance based on density of burrows for either the MNKA ($F = 0.95$, d.f. = 1, 4, $p = 0.38$) or the MAGC ($F = 0.59$, d.f. = 1, 4, $p = 0.49$). Additionally, the mean values for respective burrow classes showed no pattern with respect to estimates of population size (Figure 2a).

Estimates of prairie dog population size relative to burrow classification showed a different pattern in the period following juvenile emergence. Population estimates made with mark-resight were significantly related to burrow classification ($F = 34.20$, d.f. = 1, 4, $p < 0.01$) (Figure 2b). Similarly, estimates derived from the MNKA were also significantly related to burrow classification ($F = 8.53$, d.f. = 1, 4, $p = 0.04$). The mean value of the MNKA was lowest for those estimates made from the low-density burrow class and highest for the high-density burrow class, although the latter was not different from the medium density class (Figure 2b). There was not a significant statistical relationship between the density of burrows and population estimates made with either the MAGC ($F = 0.01$, d.f. = 1, 4, $p = 0.94$) or mark-recapture ($F = 1.35$, d.f. = 1, 4, $p = 0.31$) for the period following juvenile emergence (Figure 2b).

When we increased sample size by using MAGC across all sites where this estimate was made ($n = 12$), we failed to detect a significant relationship with burrow classification for both the period prior to ($F = 0.59$, d.f. = 1, 4, $p = 0.31$) and following juvenile emergence ($F = 0.24$, d.f. = 1, 9, $p = 0.63$).

Sighting probability

The mean sighting probability for all colonies and sampling periods was 0.25 (SD = 0.15, n = 35). The range of sighting probabilities was large 0.03 – 0.62 and estimates fell below 0.10 on five of 47 resight scans. A factorial ANOVA using the arcsine-

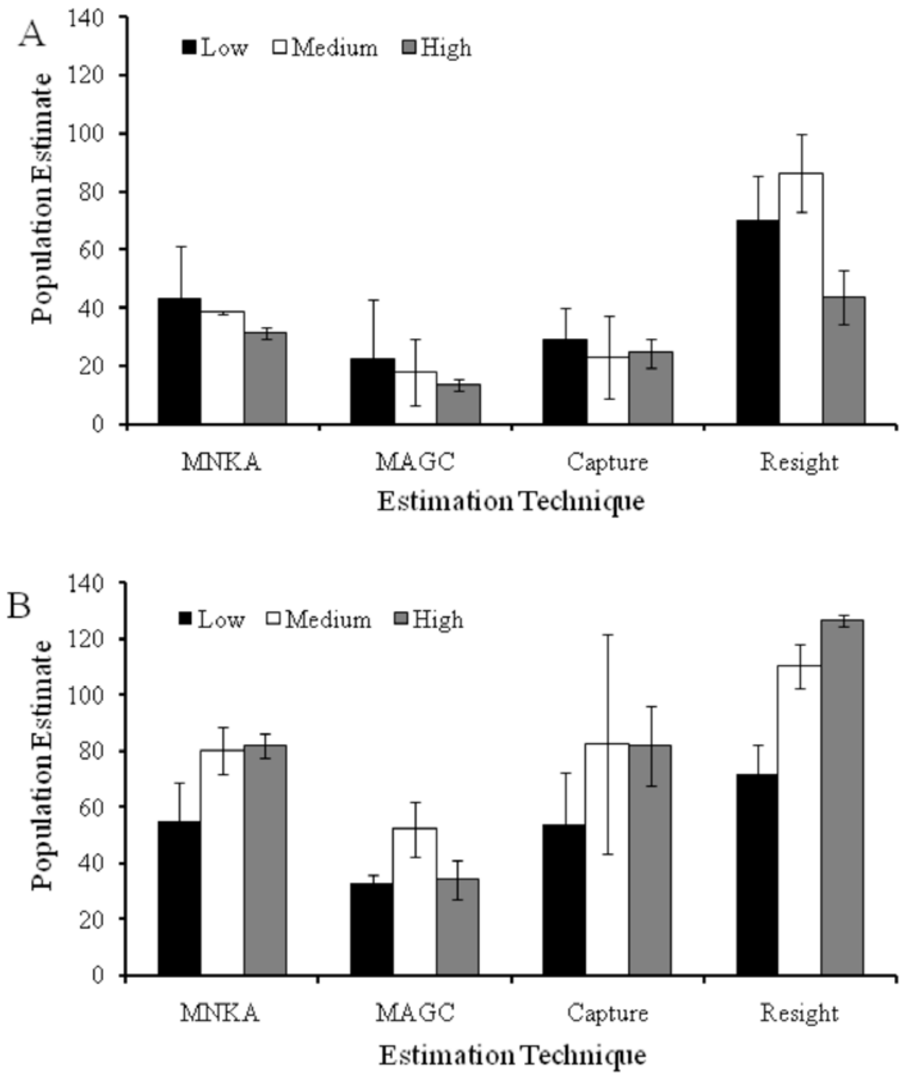

Figure 2: Average population estimate for three classes of burrow density (Low, Medium and High) from four estimation approaches: minimum number of animals known alive (MNKA), maximum above ground counts (MAGC), mark-recapture (Capture) and mark-resight (Resight). A. Estimates prior to the emergence of juveniles. B. Estimates following emergence of juveniles.

transformed sighting probabilities indicated significant effects due to colony ($F = 3.24$, d.f. = 5, $p = 0.02$) and time period ($F = 15.07$, d.f. = 1, $p < 0.01$). Additionally, there was an interaction between these two main effects ($F = 3.47$, d.f. = 5, $p = 0.01$; Figure 3).

Differences in sighting probability among colonies were difficult to assess given the interaction between colony and time. Post-hoc tests for differences in means using Fisher's Least Significant Difference demonstrated that MD1 had a significantly higher ($p < 0.05$) sighting probability than all other colonies during the pre-emergence time period. Additionally, HD1 was found to be significantly different from LD1 and MD2, however, there were no statistical differences between any other colonies during the pre-emergence time period (Figure 3). For the period following juvenile emergence we could not detect a statistical difference in sighting probability among colonies. Temporal differences in sighting probability were the result of lower sighting probabilities during the pre-emergence period ($\overline{X} = 0.20$, SD = 0.14, n = 12) compared to the post-emergence period ($\overline{X} = 0.32$, SD = 0.13, n = 12). Though differences in sighting probability indicated that our ability to observe prairie dogs changed seasonally and differed among colonies, the mechanisms responsible are unknown at this point.

Accounting for sighting probability is a necessary component of estimating population size if the MAGC is used. Population estimates derived by correcting MAGC with sighting probability were significantly related to estimates made with mark-resight ($F = 69.84$, $p < 0.001$, $R^2 = 0.87$). The high value of the coefficient of determination (R^2) indicated that this simple correction of the MAGC produced population estimates that were highly related to population estimates made with the more robust mark-resight estimator. This was in contrast to the relatively weak relationship we observed in the correlation between mark-resight and uncorrected values of the MAGC.

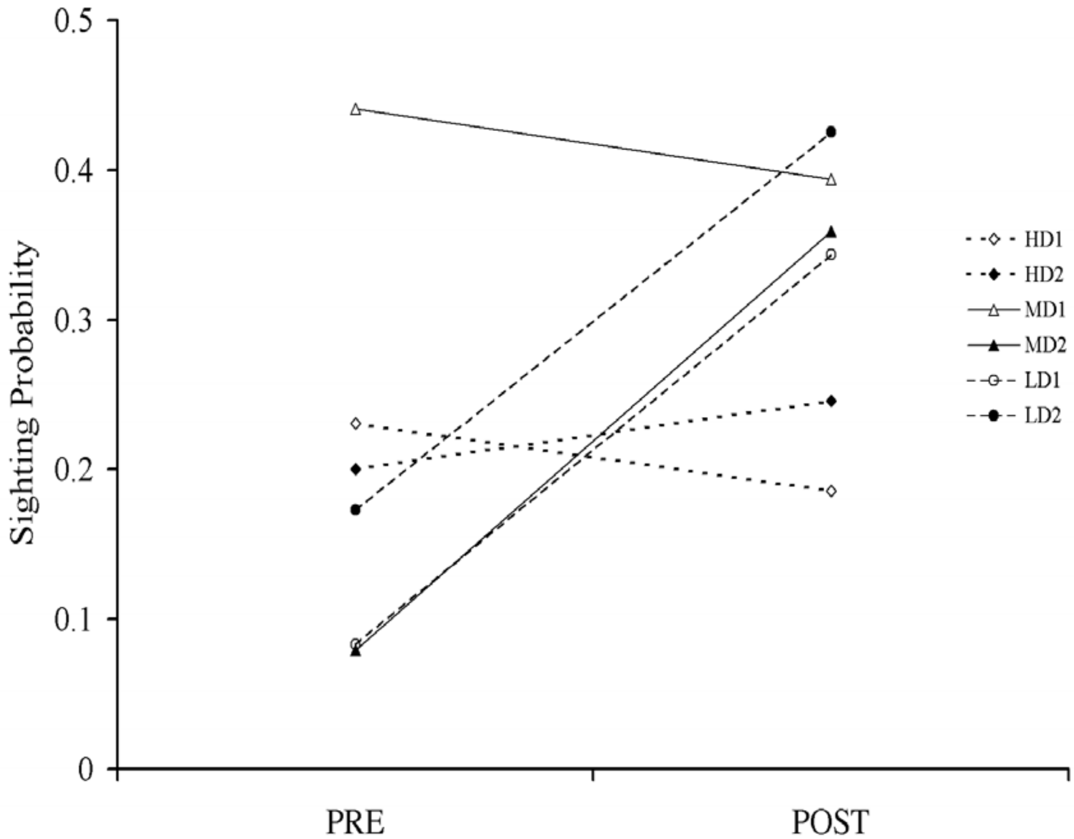

Figure 3: Average sighting probability for six colonies of Gunnison's prairie dogs pre and post juvenile emergence.

Discussion

Unbiased estimation of prairie dog abundance in the Aubrey Valley is crucial to managing and conserving black-footed ferrets. Estimates of the density of active burrows were unrelated to any estimate of prairie dog population size during the period prior to juvenile emergence (Figure 2a). Following juvenile emergence we were able to detect a significant relationship between the density of prairie dog burrows and prairie dog abundance for the MNKA and mark-resight estimation approaches (Figures 2b). Despite this, we emphasize that these results are the product of only six total observations (2 per burrow density class), and therefore cannot be considered definitive evidence that the density of prairie dog burrows is a consistent and unbiased index of the density of prairie dogs. Several studies have demonstrated that counts of active burrows were unrelated to estimates of prairie dog density (Menkens et al. 1988; Powell et al. 1994; Severson and Plumb 1998; Biggins et al. 2006). To our knowledge, however, this is the only study that has explored this relationship in Gunnison's prairie dog. Therefore, our result is potentially important especially if the positive relationship between the number of active burrows and the abundance of Gunnison's prairie dogs is supported by additional studies with larger sample sizes and therefore greater statistical power. Consequently, we advocate further research to establish a definitive relationship between the density of prairie dog burrows and estimates of the density of prairie dogs based on more robust approaches and a larger sample size, and propose a method to better estimate prairie dog abundance and density.

All estimation methods show similar patterns of abundance but only mark-resight is consistently above the minimum population threshold (i.e., MNKA). Moreover, we found a relationship between the density of active burrows and the estimated density of prairie dogs only during the period following juvenile emergence and only with the MNKA and mark-resight approaches. Sighting probability is variable through time and space, however, and an understanding of the mechanisms controlling it have the potential to facilitate more reliable population estimates when sighting probability is used in conjunction with MAGC to estimate population size. Mark-resight provides a means to estimate both sighting probably and population size and when estimates of sighting probability are used to correct MAGC, the latter could be used as an effective method to sample prairie dog colonies over a large area (Facka et al. 2008).

Estimates of population size made with mark-resight indicate that there is an average density of 16.6 (SD = 5.46) prairie dogs/ha prior to juvenile emergence across the 6 colonies. Prairie dog densities increased following juvenile emergence to 25.7 (SD = 17.88) prairie dogs/ha. Estimates from mark-recapture show similar trends between seasons with a pre-emergence density of 6.4 (SD = 2.21) prairie dogs/ha and post-emergence density of 18.20 (SD = 6.23) prairie dogs/ha. Despite this similarity in pattern, estimates made with mark-recapture were much lower than estimates derived with mark-resight and were below the minimum population size (MNKA) 75% percent of the time. Though true population size was unknown, mark-resight estimates were consistent with prior density estimates of Gunnison's prairie dogs. Cully et al. (1997) reported densities of 28 – 50 individuals/ha in northern New Mexico, whereas Rayor (1985) described densities varying on two colonies from 16 to 59 prairie dogs/ha in Colorado. In addition, a study closer to the Aubrey Valley (Flagstaff, AZ) reported densities from 48 - 89 prairie dogs/ha (Travis et al. 1995).

King et al. (2005) used counts of active burrows to estimate the mean density of prairie dogs in the Aubrey Valley at 7.82 (range 5.65 – 14.78) prairie dogs/ha during the summer of 2004. Though measured during a different time frame, this value is considerably lower than our density estimates and lower than density estimates of Gunnison's prairie dogs in other areas (Cully et al. 1997, Rayor 1985, Travis et al. 1995).

In sum, it appears that counts of active burrows represent an inaccurate picture of absolute prairie dog abundance (density) throughout the Aubrey Valley. If correct, these results would suggest that managers adopt, at least in part, a monitoring strategy that estimates how biased burrow counts are and that will provide information on the relationship between the density of prairie dogs and the density of their burrows (see Facka et al. 2008).

An alternate approach to estimating prairie dog abundance is to use maximum above ground counts adjusted for sighting probability. Though our population estimates from mark-resight were not directly related to the MAGC, we subsequently found that when we accounted for sighting probability the MAGC explained 87% of the variation in mark-resight estimates. The relationship between sighting probability, population size and MAGC was important because sighting probability varied from as little as 0.08 to as much as 0.44 during the same season. If these two extreme values were observed at two colonies of equivalent population size (e.g. 100 animals) than estimates of relative abundance based on MAGC alone would have indicated populations of 8 and 44, respectively. Obviously, these results would be misleading without an estimate of sighting probability. In this study, we controlled for sighting probability, which presumably allows the MAGC to be a more accurate estimator of population size. Previous studies that have suggested a positive correlation between MAGC and population estimates have used mark-recapture as an unbiased estimate of population size (Menkens and Anderson 1993, Severson and Plumb 1998), but we found that mark-recapture typically underestimates even the MNKA. Therefore, if MAGC is going to be used as an estimate of population size, we recommend that estimates of sighting probability be used to correct the MAGC, rather than incorporating some relationship with mark-recapture, because the latter yields an estimate of detectability that is derived from trapping animals whereas mark-resight uses an estimate of detectability based on observing them.

Models that attempt to estimate population abundance from MAGC must estimate sighting probability, assume sighting probability is constant, or accurately predict sighting probability. The scope of this study prevented us from creating models that could predict sighting probability for future studies or surveys in the Aubrey Valley. Other studies have shown a relationship between sighting probability and environmental factors such as the amount of vegetative cover, temperature or time of day (Powell et al. 1994, Anderson 1996, Craig and Reynolds 2004), and these would be important variables to consider if future studies are undertaken. Even though the mechanisms were not addressed, use of an average sighting probability derived from a large sample size could still be used to adjust MAGC and would provide a more accurate estimate of prairie dog density than counts of active burrows because the latter are categorical (i.e., low, medium or high) and the former is an actual estimate that appears to be relatively unbiased when compared to estimates derived by mark-resight. Such an approach could be applied at relatively large scales. In the case of the Aubrey Valley, MAGCs corrected for sighting probability and recorded at random locations distributed across the valley would yield more robust estimates of prairie dog population size than would valley-wide estimates of the distribution of the density of active burrows alone. If a strong statistical relationship between a corrected MAGC and density of burrows could be found, however, than a robust estimate of the total number of prairie dogs within the valley could be made using a combination of the two methods.

One additional comment concerns the use of counts of active burrows to gauge the whereabouts of reintroduced ferrets for purposes of monitoring. It is conceivable that the number of active burrows maybe an appropriate index to finding ferrets especially if this is the very cue that ferrets use to find areas where prairie dogs are abundant. More research is needed to address the relationship between the abundance of prairie dogs, the density of active burrows and the space use patterns of ferrets.

In summary, though we found evidence that the density of prairie dog burrows relates to the actual abundance of prairie dogs after juvenile emergence, we must reiterate that this relationship is based on limited data and that counts of active burrows are only a relative index of abundance rather than an estimate of abundance. Consequently, estimates of prairie dog abundance in the Aubrey Valley using the density of active burrows are likely suspect. Alternate more robust methods of population estimation should be employed if more accurate assessments of prairie dog abundance are the goal. We found that mark-resight is the only estimation approach that was not clearly negatively biased. Further, estimates of relative abundance that rely exclusively on MAGC may give inaccurate information if they are not adjusted for sighting probability. Sighting probability is highly variable in both space and time, and the complicated relationship between estimates of abundance and MAGC needs to be carefully considered if the latter is to be used as an estimate of abundance. Despite this complication, we found that when MAGC is corrected by sighting probability, it is a reasonable estimate of population size if estimates of prairie dog abundance based on mark-resight are reflective of true population size. A sampling protocol that incorporates mark-resight as a method to estimate population size, density and sighting probability in conjunction with large-scale, stratified use of MAGC could improve estimates of total prairie dog numbers in the Aubrey Valley and thereby improve management of the critically endangered black-footed ferret.

References

Anderson, C. R. J. 1996. Moose sightability model developed from helicopter surveys. Wildlife Society Bulletin 24:247-259.

Burnham, K. P., and D. R. Anderson. 1998. Model selection and inference: A practical information-theoretic approach. Springer, New York.

Biggins, D. E., B. J. Miller, L. R. Hanebury, B. Oakleaf, A. H. Farmer, R. Crete, and A. Dood. 1993. Management of Prairie dog complexes for the reintroduction of the Black-footed ferret. Pages 73-88 in J. L. Oldemeyer, D. E. Biggins, and B. J. Miller editors. Proceedings of the symposium on the management of prairie dog complexes for the reintroduction of the black-footed ferret. U.S. Fish and Wildlife Service, Washington D.C.

Biggins, D. E., J. G. Sidle, D. Seery, B, and A. Ernst, E. 2006. Estimating the abundance of prairie dogs. Pages 94-108 in J. L. Hoogland, editor. Conservation of the black-tailed prairie dog: saving North America's western grasslands. Island Press, Washington D.C.

Bowden, D. C., and R. C. Kufeld. 1995. Generalized mark-resight population size estimation applied to Colorado moose. Journal of Wildlife Management 59:840-851.

Brown, D.E. (ed.). 1982. Biotic Communities of the American Southwest-United States and Mexico. Desert Plants. University of Arizona Press, Tucson, AZ. 342 pp.

Craig, B. A., and J. E. Reynolds. 2004. Determination of manatee population trends along the Atlantic coast of Florida using a Bayesian approach with temperature-adjusted aerial survey data. Marine Mammal Science 20:386-400.

Cully, J. F., Jr., A. M. Barnes, T. J. Quan, G. Maupin, and J. F. J. Cully. 1997. Dynamics of plague in a Gunnison's prairie dog colony complex from New Mexico. Journal of Wildlife Diseases 33:706-719.

Facka, A. N., P. L. Ford, and G. W. Roemer. 2008. A novel approach for assessing density and range-wide abundance of prairie dogs. Journal of Mammalogy 89: 356-364.

Henderson, F. R., P. F. Springer, and R. Adrian. 1969. The black-footed ferret in South Dakota. South Dakota Dept. Game, Fish and Parks, Technical Bulletin 4**:**1-37.

Hoogland, J. L. 1995. The black-tailed prairie dog: Social life of a burrowing mammal. University of Chicago Press, Chicago.

Hoogland, J. L. 2001. Black-tailed, Gunnison's, and Utah prairie dogs reproduce slowly. Journal of Mammalogy 82:917-927.

Hillman, C. N., and R. L. Linder. 1973. The Black-footed ferret. Pages 10 - 20 in R. L. Linder, and C. N. Hillman, editors. Black-footed ferret and prairie dog workshop, South Dakota State University, Brookings, SD.

King, C. L., J. W. Broecher, R. C. Lonsinger, A. R. Siniawski, and W. E. Van Pelt. 2005. Results of the 2004 black-footed ferret release effort in Aubrey Valley, Arizona. Nongame and Endangered Wildlife Program Technical Report, Arizona Game and Fish Department, Phoenix, Arizona.

Knowles, C. J. 1985. Observations on prairie dog *Cynomys ludovicianus* dispersal in Montana USA. Prairie Naturalist 17:33-39.

Menkens, J. G. E., B. Miller, and S. H. Anderson. 1988. White-tailed prairie dog ecology in Wyoming. Pages 34-38. Eighth Great Plains Wildlife Damage Control Workshop, Rapid City, SD.

Menkens, G. E., Jr., and S. H. Anderson. 1993. Mark-recapture and visual counts for estimating population size of white-tailed prairie dogs. Pages 67-72 in J. L. Oldemeyer, G. C. Bachman, and B. J. Miller, editors. Proceedings of the symposium on management of prairie dog complexes for the reintroduction of the black-footed ferret. US Fish and Wildlife Services Biological Reports.

Miller, B., R. P. Reading, and S. Forrest 1996. Prairie Night: Black-footed ferrets and the recovery of endangered species. Smithsonian Institution Press, Washington, DC.

Otis, D. L., K. P. Burnham, K. H. Pollock, W. R. Davidson, and F. E. Kellogg. 1978. Statistical inference from capture data on closed animal populations. Wildlife Monographs 62:1-135.

Pollock K. H., J. D. Nichols, C. Brownie, and J. E. Hines. 1990. Statistical Inferences for capture-recapture experiments. Wildlife Monographs 107:1-97.

Powell, K. L., R. J. Robel, K. E. Kemp, and M. D. Nellis. 1994. Aboveground counts of black-tailed prairie dogs: Temporal nature and relationship to burrow entrance density. Journal of Wildlife Management 58:361-366.

Rayor, L. S. 1985. Effects of habitat quality on growth, age, and first reproduction, and dispersal in Gunnison's prairie dog (*Cynomys gunnisoni*). Canadian Journal of Zoology 62:2835-2840.

Severson, K. E., and G. E. Plumb. 1998. Comparison of methods to estimate population densities of black-tailed prairie dogs. Wildlife Society Bulletin 26:859-866.

Travis, S. E., C. N. Slobodchikoff, and P. Keim. 1995. Ecological and demographic effects on intraspecific variation in the social system of prairie dogs. Ecology 76:1794-1803.

White, G. C. 1996. NOREMARK: Population estimation from mark-resighting surveys. Wildlife Society Bulletin 24:50-52.

White, G. C., and K. P. Burnham. 1999. Program MARK: Survival estimation from populations of marked animals. Bird Study 46:120-139.

Winstead, R. A., A. L. McIntire, and W. E. Van Pelt. 1998. Results of the 1999 black-footed ferret release effort in Aubrey Valley, Arizona. Nongame and Endangered Wildlife Program, Arizona Game and Fish Department, Phoenix, AZ.

Zar, J.H., 1999. Biostatistical analysis. 4th Edition. Prentice-Hall, Upper Saddle River, NJ.