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# **Aerial Population Estimates of Wild Horses (*Equus caballus*) in the Adobe Town and Salt Wells Creek Herd Management Areas Using an Integrated Simultaneous Double-Count and Sightability Bias Correction Technique**

By Bruce C. Lubow and Jason I. Ransom

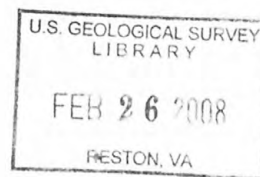
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By Bruce C. Lubow<sup>1</sup> and Jason I. Ransom<sup>2</sup>

## Abstract

An aerial survey technique combining simultaneous double-count and sightability bias correction methodologies was used to estimate the population of wild horses inhabiting Adobe Town and Salt Wells Creek Herd Management Areas, Wyoming. Based on 5 surveys over 4 years, we conclude that the technique produced estimates consistent with the known number of horses removed between surveys and an annual population growth rate of 16.2 percent per year. Therefore, evidence from this series of surveys supports the validity of this survey method. Our results also indicate that the ability of aerial observers to see horse groups is very strongly dependent on skill of the individual observer, size of the horse group, and vegetation cover. It is also more modestly dependent on the ruggedness of the terrain and the position of the sun relative to the observer. We further conclude that censuses, or uncorrected raw counts, are inadequate estimates of population size for this herd. Such uncorrected counts were all undercounts in our trials, and varied in magnitude from year to year and observer to observer. As of April 2007, we estimate that the population of the Adobe Town /Salt Wells Creek complex is 906 horses with a 95 percent confidence interval ranging from 857 to 981 horses.

## Introduction

A census is defined as a total count, without error, of a population. Wildlife managers recognize that a census is not possible for most wildlife populations and that some estimation technique is necessary. Two factors contribute to this conclusion. First, aerial observers are unlikely to detect every individual in a population. Second, cost, personnel, and fatigue factors may make aerial surveys of vast areas prohibitive, necessitating estimation based on stratified random sampling of the area. Typically, one third or more of wild ungulates in the West (e.g., elk, mule deer, bighorn sheep, moose) are missed by uncorrected aerial counts (Samuel and others, 1987;

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Ackerman, 1988; Singer and Garton, 1994; Bodie and others, 1995; Bowden and Kufeld, 1995). Visibility of ungulates can vary tremendously from survey to survey depending on transect spacing and sighting factors such as snow cover, average group size, activity of the animals, tree cover, and experience of the observers (Samuel and others, 1987; Unsworth and others, 1994; Bodie and others, 1995). If sightability factors vary from survey to survey due to differences between observers and sighting conditions such as vegetation, cloud cover, snow cover, group size and others, use of one set of correction factors could be misleading. Such variability is well documented in elk. During 13 complete aerial surveys of an elk population, detection of marked elk ranged from only 41 percent under poor conditions (deep snows, small elk groups, high tree cover) to 91 percent under the best conditions (shallow, soft snow; very cold temperatures; large elk groups; large open areas) (Singer and Garton, 1994).

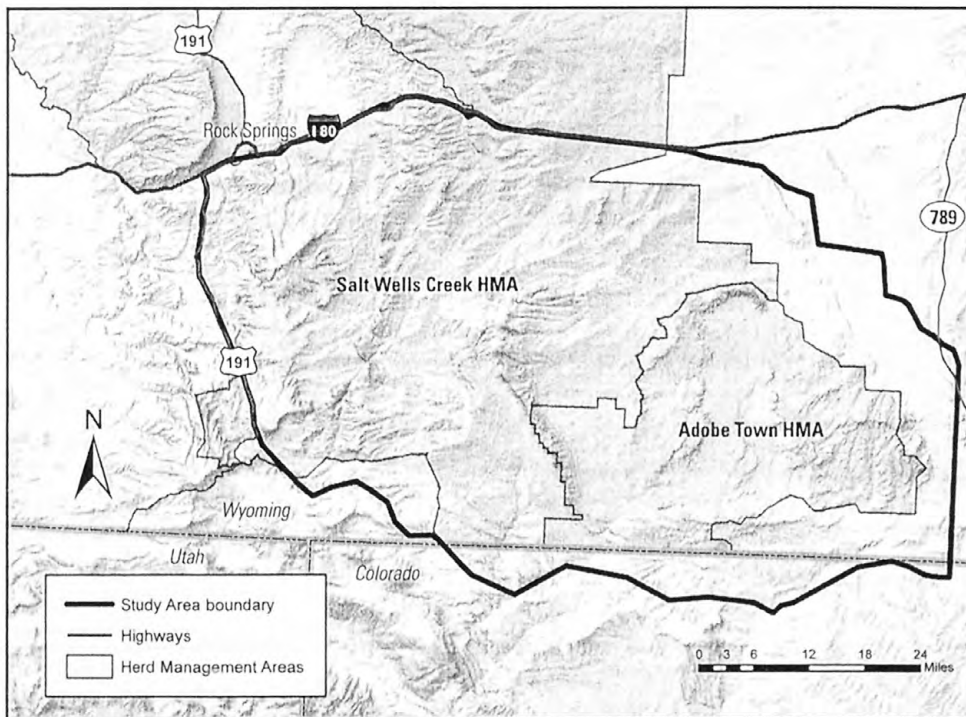
Two commonly used population estimation techniques are the simultaneous double-count and the sightability bias correction model. Simultaneous double-count is performed with two observers independently observing and recording data on groups of individuals, from which sighting rates are estimated by comparing the sighting records of the two observers. It is a form of mark-recapture in that animals seen by the one observer are the “marked” groups, and those that are also seen by the other observer are “resighted.” Sighting probabilities for both observers can be computed from this information using Lincoln-Petersen calculations to generate a population estimate (Seber, 1973). The sightability bias correction model technique works in the opposite direction and uses a model of the sighting probability for groups of individuals, which traditionally has been precalibrated through a series of marked or ground-truthed sighting trials to determine which covariates (such as group size, percent tree and shrub cover that will hide animals, percent snow cover, observer experience, survey intensity) influence sightability. This approach was developed in Idaho for elk (Samuel and others, 1987) and thus it is often referred to as the Idaho Sightability Model.

Many traditional population estimation techniques such as simultaneous double-count and sightability bias correction models have inherent limitations, yet integrated techniques that use information from two or more such estimation methods can overcome many of the deficiencies of the individual techniques and provide greater power and efficiency (Manly and others, 1996; Borchers and others, 1998a, 1998b; Laake, 1999). For example, a major difficulty of the simultaneous double-count technique is ensuring similar sighting probabilities for all animals by each observer (Seber, 1973). This can be resolved by modeling sightability using covariates in a manner similar to the sightability bias correction technique (Samuel and others, 1987). However, unlike the traditional sightability bias correction method, multiple observers provide sufficient information to estimate sighting models for each observer from a single survey. Therefore, no precalibration of the model is required, and the often untenable assumption that the initial calibration applies uniformly over space, time, and observers is eliminated.

A stated goal of the Bureau of Land Management’s (BLM) Wild Horse and Burro Program is to conduct a population survey of each herd management area at least every 4 years. However, few and infrequent surveys are inadequate for providing reliable information on which to base management decisions. Wild horse and burro managers need standardized, tested, defensible, cost-effective, yet easy-to-use aerial population estimation techniques for wild horse and burro herds in a range of habitat types and across a range of population sizes and densities. The accuracy and precision of current wild horse survey methods has not been rigorously tested; thus, a statistically valid estimation technique with confidence intervals is needed. As part of a larger research project aimed at addressing these needs (Lubow and others, 2004), we conducted a series of aerial population estimation surveys on the Adobe Town/Salt Wells Creek Herd Management Area (HMA) complex in Wyoming.

## Study Area

The study area is composed of two HMAs that share a common, unobstructed border, with Adobe Town HMA on the east and Salt Wells Creek HMA on the west, as well as additional lands where horses may disperse outside of the HMA boundaries (fig. 1). The area totals 850,115 ha, with 474,555 ha lying in Salt Wells Creek HMA, 193,880 ha in Adobe Town HMA, and 181,680 ha outside of the HMAs. The complex lies in Sweetwater and Carbon Counties, Wyoming, roughly bordered on the north by US Interstate 80, on the south by the Colorado State line, on the west by US Highway 191, and on the east by Wyoming Highway 789. The area is characterized by sagebrush steppe and desert biomes with elevations ranging from 1,973 m along Sand Creek Wash to over 2,440 m on Black's Butte (U.S. Department of the Interior, 2006). Annual precipitation ranges from less than 178 mm to more than 305 mm per year and falls primarily from April through June, with the remainder falling in high-intensity summer thunderstorms and winter snowfall. Runoff from drainages is captured in reservoirs and is the primary source of water for wild horses (*Equus caballus*), livestock (*Bos* spp. and *Ovis aries*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*). The study area is characterized by diverse plant communities that reflect wide variation in soils, topography, and geology. Predominant vegetation includes Wyoming big sagebrush (*Artemisia tridentata*), Gardner's saltbush (*Atriplex gardneri*), greasewood (*Sarcobatus vermiculatus*), bluebunch wheatgrass (*Pseudoroegneria spicata*), western wheatgrass (*Pascopyrum smithii*), and Indian ricegrass (*Oryzopsis hymenoides*). Some tree cover is present in the study area and occurs primarily in the south and west, where stands of piñon pine (*Pinus edulis*) and juniper (*Juniperus* sp.) populate the hills.



**Figure 1.** Location of Adobe Town and Salt Wells Creek Herd Management Areas, Wyoming, showing the boundary of the survey area.

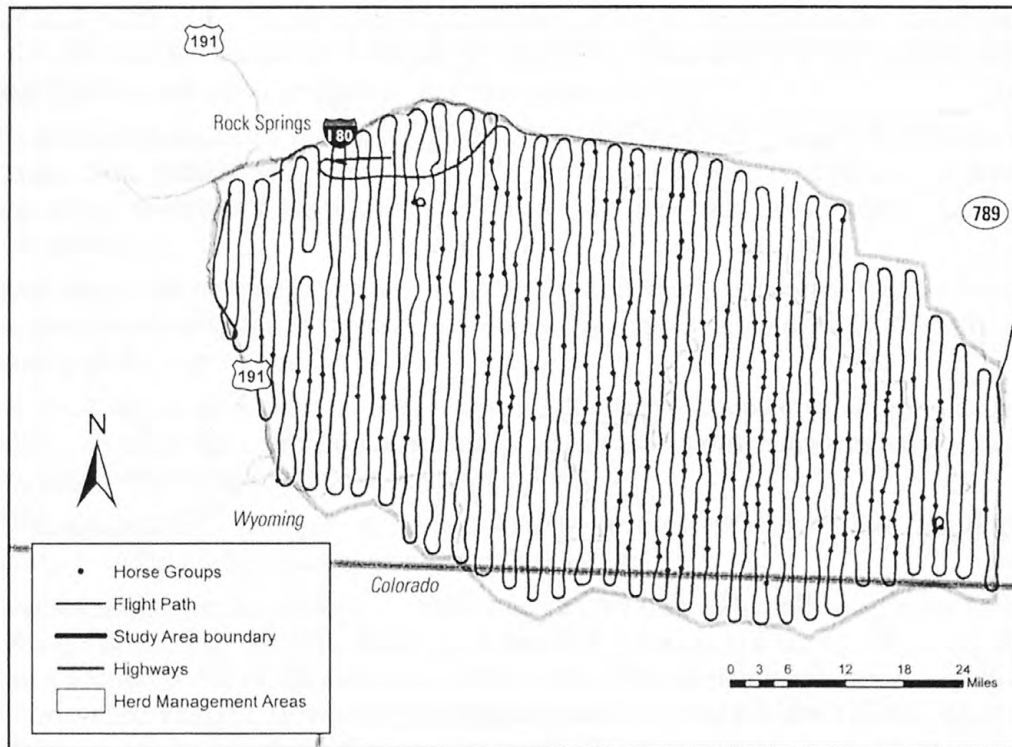


# Methods

## Aerial Surveys

To investigate an integrated aerial survey technique using the Adobe Town/Salt Wells Creek wild horse population, we performed 5 aerial surveys using a method that combined simultaneous double-count with sightability bias correction, where a known number of animals was removed between two pairs of surveys. Flights were conducted using a Cessna 210 fixed-wing aircraft, maintaining an above-ground altitude of approximately 152–183 m and airspeed of approximately 140–160 nautical miles per hour. Transects were flown north/south and spaced approximately 1.5 minutes of longitude apart (1.3 miles or 2.1 km at 41° latitude), using the same survey boundaries for each survey (fig. 2). Flight paths and group locations were recorded using a Garmin 76S Map handheld global positioning system (GPS) unit with an external antenna mounted in the front window.

The surveys were conducted on 5 occasions: (1) March 2004, (2) July 2005, (3) April 2006, (4) December 2006, and (5) April 2007. These surveys were a combined effort by BLM and USGS; survey crews were composed of individuals from both agencies, as well as an observer from the



**Figure 2.** Flight path and locations of horse groups in the Adobe Town/Salt Wells Creek study area during the April 2007 survey. The same transect design was used for all 5 surveys.



Rock Springs Grazing Association (with one exception, discussed below). The surveys contributed to the improvement of methodologies, and to testing their validity, as part of an ongoing research study. They also provided additional information for management. Surveys 2, 3, and 5 were all conducted according to the final protocols. Survey 1 was conducted differently since final protocols were not yet developed, and Survey 4 was interrupted by extreme weather. Surveys 2-5 consisted of 3 observers in addition to the pilot, whereas only 2 observers were used on Survey 1. The pilot was not considered an observer since his primary duty was flying the aircraft.

Surveys 2, 3, and 5 used the right side of the aircraft for the integrated technique by having one observer in the front seat and one observer in the rear seat directly behind him. Audio and visual isolation were maintained during the survey, with the provision that once a group of horses had passed the rear observer, the observers were free to discuss the count number and circle back if confirmation was needed. This procedure did not affect the sightability record; but ensured that the correct number of horses was recorded. The third observer, in the left rear seat, recorded the same data without being double-counted. At each fuel stop, the rear observers switched sides so that each would be double-counted during similar sighting conditions throughout the survey. Deviations from this methodology during surveys 1 and 4 are detailed below.

Survey 1 was the first survey of this population conducted under the research protocol and involving USGS personnel. Survey 1 differed substantially from subsequent 4 surveys in the following ways:

1. The survey of Adobe Town, where the majority of horses were located during Survey 1, was done with only a single rear-seat observer, who switched from one side of the airplane to the other so as to maintain a constant direction of observation as the airplane turned. All other flights were conducted with two rear observers.
2. The covariates collected during the 2004 survey differed from those gathered in subsequent surveys. Specifically, vegetation cover and sun direction were not recorded in 2004. Vegetation cover has since proven to be especially important to estimating sighting probabilities.
3. A different front-seat observer was used for the Salt Wells portion of the 2004 survey than was used in all subsequent surveys. Consequently, data available to estimate this observer's sighting ability are minimal.
4. The 2004 survey covered only the area within the HMA boundaries; areas outside those boundaries were not searched for horses that had strayed onto adjacent non-BLM land. This deficiency was corrected in later surveys.
5. The dual-observer technique was new to all but one crewmember on this first flight; therefore, inexperience may have affected the results.

Survey 4, in December 2006, was interrupted by weather. The full survey methodology was used over 3 days before bad weather interrupted the survey for several days. Following the interruption, a second phase of the survey covered most of the remaining area and resulted in 333 additional horse observations. However, this second phase was not included in the research study because timing caused by weather delays prevented USGS involvement in this portion of the survey. As a result, the simultaneous double-count methodology was not used and covariates were not recorded.

## **Data Analysis**

Program MARK (White and Burnham, 1999; White and others, 2001) was used to model the simultaneous double-count data. The Huggins closed-capture model structure (Huggins, 1989;

1991) implemented in program MARK was chosen because it enables use of covariates. This method uses a conditional likelihood approach to model the probability of sighting each horse group based on the covariates recorded for that group. We considered covariates for survey occasion, observer, seat location (front or rear), group size, distance from aircraft, rugged versus flat terrain, type of vegetation cover, percent vegetation cover, percent snow cover, sun position, and movement of the horses. In addition, the interactions of group size with open vegetation and group size with rugged terrain were considered.

Separate sightability models were fitted for Survey 1 versus the remaining 4 surveys combined, because the methods used and data collected for Survey 1 were incompatible with the other 4. The latter model of sighting probabilities (based on Surveys 2-5) was able to draw on this much larger dataset to obtain the most precise possible estimates, but individual population estimates were made for each survey.

To handle Survey 4's two phases and their different methods, we used only the results of the first phase in our modeling and analysis to determine sighting probabilities for each horse group individually. We then used the average sighting probability for that entire phase to correct the additional raw count from the second phase and added these two components together to reach a final estimate. We also assumed that the error rate (coefficient of variation) for the second phase was 30 percent, because the data collected provide no means to estimate the precision statistically. We chose this high error rate to allow for the differences in observers and methods and for any other unknown errors.

Horses were assumed to be available to either the two right-side observers or to the single left-side observer and never available to both. Groups seen only by the pilot were dropped from the analysis because pilot survey effort was highly variable. Rear-seat observers were rotated so that each could be tested against the front-seat observer, enabling estimation of unique sighting probability models for each observer.

Approximately 6.8 percent of the survey area fell within a 137-m strip underneath the airplane's flight path that was not visible to the observers while flying directly overhead. However, in this analysis, we did not increase our estimates to account for horses that might have been missed within this area. This is justified by assuming that horses located in this strip might run from the approaching aircraft and become visible, or that they could be spotted from an adjacent transect with some probability. This assumption also minimizes the possibility of an overestimate. We also found that the population model discussed below fit better without an adjustment for horses missed under the flight path.

Final population estimates were computed using AICc model weights (Burnham and Anderson, 2002) to weight the complete set of tested models. This process accounts for the inherent uncertainty in the selection of the model from the candidate set, thereby widening the confidence intervals to realistically reflect this often-overlooked source of uncertainty. Population estimates were computed using the sighting probabilities for each individual group to correct for groups not seen (Huggins, 1989, 1991). The observed group sizes were applied to the corrected group number and summed to obtain the population estimate.

A bootstrap procedure was used to compute confidence intervals for the population estimates (Wong, 1996). Alternative sighting models were fit to the bootstrapped data; thus, variation in estimates includes that caused by sightability model selection, model parameter estimation, and the binomial sighting process itself. Confidence intervals were computed assuming lognormal errors.

## Population Modeling

A simple population model was constructed to project the population from one time period to the next. The population increase from 1 year to the next was projected as a constant percentage of the previous population. This combines births and deaths, which is necessary because no data on these separate processes are available for this population. A removal of 1,200 horses occurred in September 2005, and another 846 horses were removed in January 2007. A much larger removal of 2,350 horses occurred in August 2003, before the first survey in this study. These known removals were subtracted from the population projections. Thus, the model required only two parameters to be estimated: the initial population size and the annual population growth rate (net of births and deaths).

The population model was fit to the field estimates of population size following the methods of White and Lubow (2002). Optimum model fit was determined by finding the parameter values that minimized the squared differences between model values and field estimates, weighted by the precision of the field estimates. The estimate from Survey 1 was excluded in the fitting due to the different methodology employed in that entire survey; however, the estimates from Survey 4 were included, despite the noted differences in methodology for a portion of this survey.

## Results

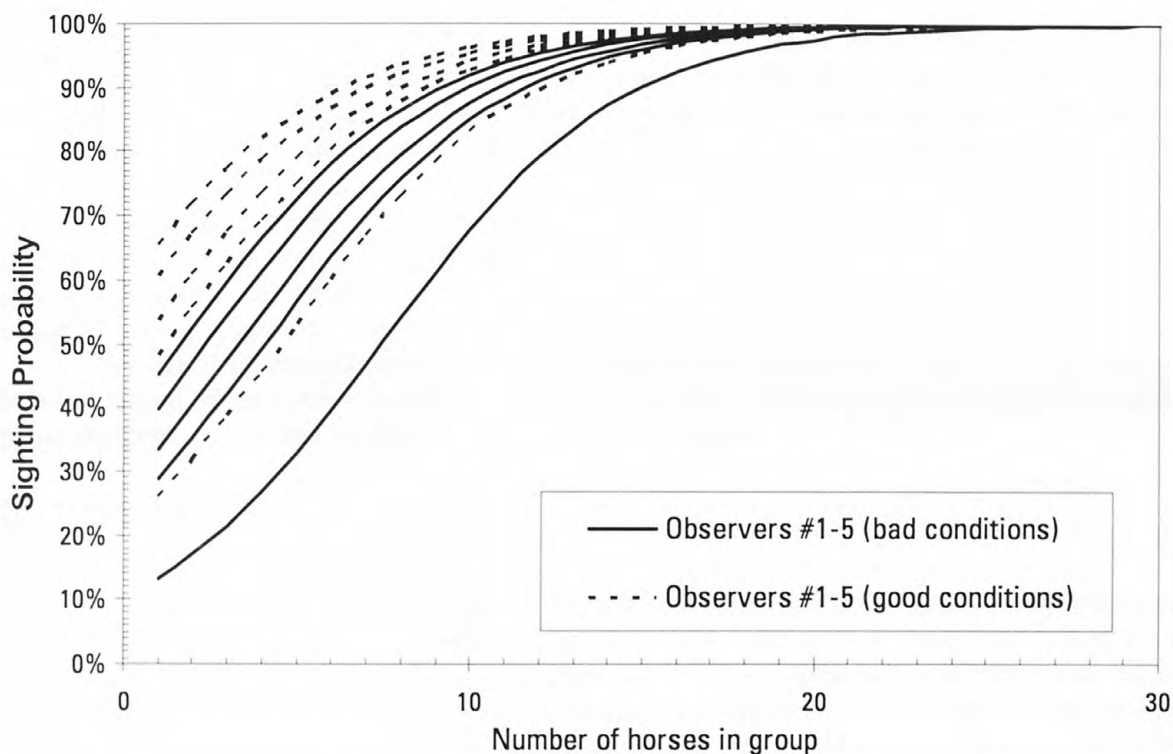
Of 15 models examined, the model most strongly supported by the complete dataset (Surveys 2–5) included separate intercept parameters for each observer and common slope parameters across observers for the effects of group size, presence of vegetation, terrain, and relative sun position. Sighting probability differed markedly among observers and was very strongly dependent on group size (fig. 3). Estimated sighting probability for a single horse varied from as low as 13.2 percent to as high as 65.5 percent, depending on the observer and sighting conditions. Sighting probability increased sharply with group size; essentially all groups larger than 20 horses were seen. Presence of vegetation, rugged terrain, and looking toward the sun on a clear day all reduced sighting probability compared to the opposite conditions.

The most general model (most parameters) fit the data very well and showed no evidence of over-dispersion. The variance inflation factor was 1.0, exactly the expected value for a binomial process with full independence. Alternative models with sufficient support to be considered differed in the presence or absence of the rugged terrain covariate, the inclusion of a sun elevation-angle covariate, and additive effects of the survey date (i.e., a general increase or decrease in sighting probability for an entire survey). The best model received 35.6 percent of the weight and only the top 5 received >5 percent each. The population estimates were based on weighted-average estimates from these top 5 models.

Actual numbers of horses seen along with the statistical estimates are provided in table 1. Average sighting rates for entire surveys ranged between 70.2 percent and 84.2 percent. Across the 4 most recent surveys, average sighting probability was 77.1 percent. Estimated error rates (coefficient of variation) for population estimates ranged from 3.1 percent to 8.1 percent across the surveys.

There was a single pair of surveys conducted before and after known gather and removal operations without an intervening period of births. The removal of 846 horses in January 2007 is significantly smaller ( $P < 0.016$ ) than the difference in our December 2006 and April 2007 estimates. The estimated change is 1,180 [909 – 1,451]. The actual change does not fall within the 95 percent confidence interval.





**Figure 3.** Sighting probabilities by horse group size and observer. Good conditions (dashed lines) correspond to no obscuring vegetation (shrubs or trees), non-rugged terrain, and sun not shining toward observer. Bad conditions (solid lines) are the reverse. The set of 5 lines of each type represent sighting models for the 5 different observers who participated in the surveys.

**Table 1.** Combined population estimates for the Adobe Town and Salt Wells Creek Herd Management Areas.

Survey date	Horses seen (No.)	Population estimate (No.)	Population seen (%)	SE	CV (%)	LCL (95%)	UCL (95%)
Mar-04 <sup>1</sup>	1,253	1,536	81.6	75.0	4.9	1,423	1,725
Jul-05	1,552	2,211	70.2	113.5	5.1	2,023	2,473
Apr-06	1,189	1,541	77.2	47.5	3.1	1,460	1,647
Dec-06 <sup>2</sup>	1,385	2,088	82.3	170.1	8.1	1,875	2,591
Apr-07	763	906	84.2	31.1	3.4	857	981

<sup>1</sup> Estimate made using different survey methods and different analysis methods.

<sup>2</sup> The December 2006 estimate is based on two phases of the survey, only one of which used the same methods as other surveys.

The fitted population model (fig. 4) produced a population growth rate estimate of 16.2 percent/year. The population model estimates are all within the 95 percent confidence intervals of the field estimates, excluding the March 2004 estimate, which was not included in the model fitting. This estimate from Survey 1 is clearly an outlier, 24 percent lower than the fitted population model projects that it should have been.

The model estimate for December 2006 is near the lower 95 percent confidence bound for that estimate despite the estimate having a larger confidence interval than the others. The low precision is due to the assumed (rather than statistically estimated) low precision for the second phase of the survey, which was not conducted using the research methodology.

We currently estimate 906 [857–981] horses in this population. If the lower confidence interval bound of the current estimate is assumed and the 16.2 percent growth rate is applied, the projected population later in 2007 will be at least 996 horses.

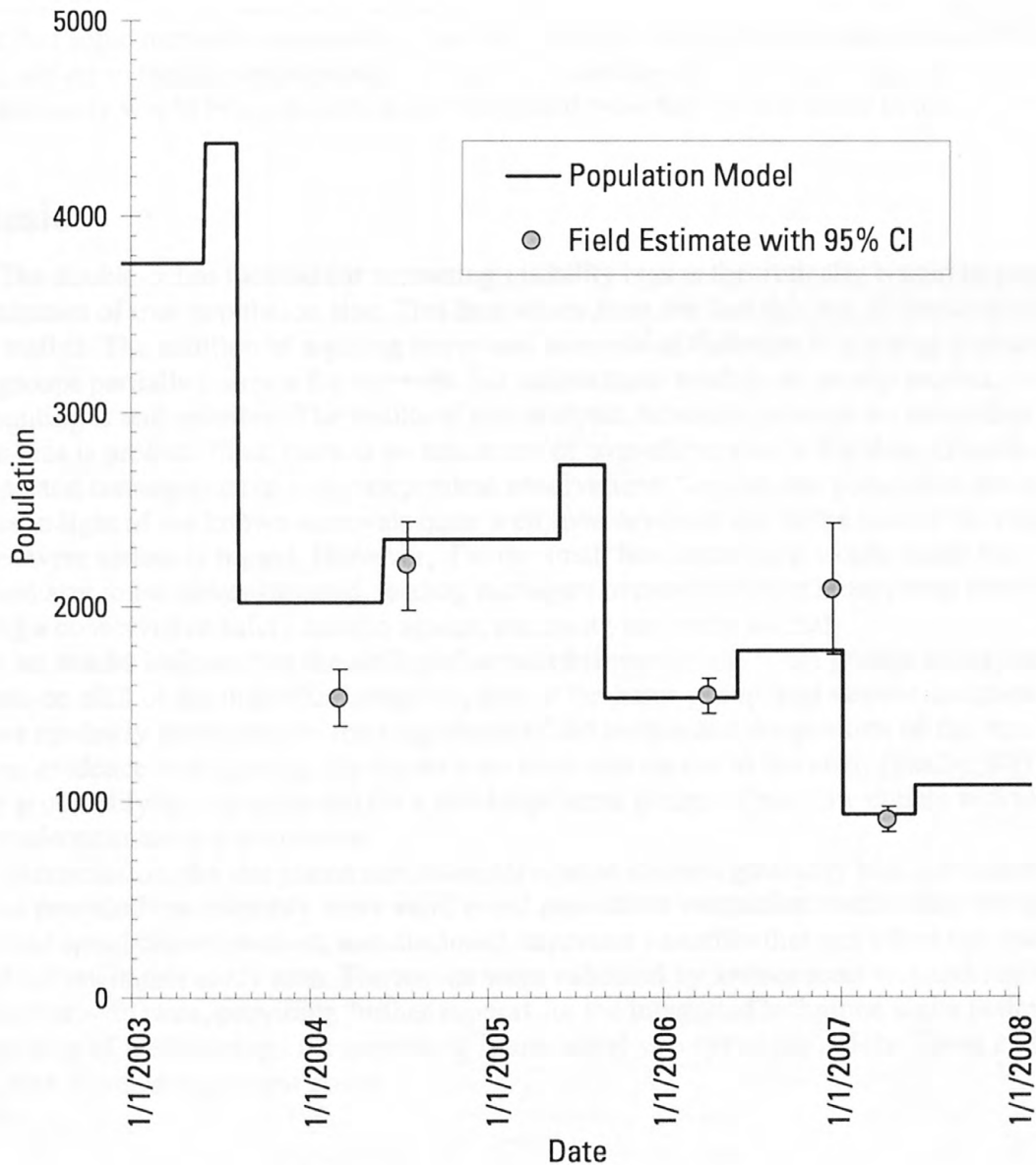
## Discussion

The fitted population model places the five individual estimates into a comprehensive picture. In fitting the population model, all the individual estimates are integrated and combined with simple population dynamics to find a trajectory for this population consistent with all of the available information. The fitted population model falls within the 95 percent confidence intervals of the field population estimates for all estimates except that in 2004 (which was excluded in the model fitting due to differences in methods used for this early estimate). The model growth rate that provides the best fit is 16.2 percent, which is certainly plausible based on observed annual growth rates in other herds, which range from 15 percent to 25 percent per year (Eberhardt and others 1982; Garrott and Taylor, 1990; Garrott and others, 1991). This provides some confirmation that the individual estimates are valid, because they all can be plausibly linked to each other through known removals and a realistic estimate of population growth rate.

Given the population growth rate estimated in this analysis and the large removal that occurred just prior to the first survey, it is possible to project backwards in time to estimate the maximum population size reached prior to this series of removals. This calculation estimates that 4,370 horses were present in 2003, after the birth of young and before the removal later that summer.

In light of all of the subsequent evidence, the 2004 population estimate (Survey 1) was considerably biased (low). The fitted population model suggests that the population in 2004 should have been 2020 horses, which is 484 horses more than our estimate at the time. Thus, it appears that the estimate was low by 24 percent. The numerous differences in methodology, which have since been improved, are undoubtedly the reason that this first estimate was so low.

Although the population model fits within the 95 percent confidence intervals of the December 2006 field estimate, it is close to the lower bound, suggesting that this field estimate may be too high. The most plausible reason for this is that the second phase of the survey was conducted several days after the end of the first phase because of weather conditions. It is possible that horses moved during the intervening period and that some were erroneously counted twice (during both phases). The difference in methods applied during the second phase may also have contributed unknown errors to this estimate.



**Figure 4.** Population projection model fitted to observed field estimates of population size, shown with 95 percent confidence intervals. The field estimate in 2004 was excluded from the model fitting because of substantial differences in methodology between that one and the remaining four estimates. Increasing population segments represent estimated new recruitment of young net of any natural mortality; decreasing segments represent known management removals. An annual population growth rate of 16.2 percent was estimated to produce the best fit to the data.



The problem with the December 2006 estimate also impacts the comparison of the population before and after the known removal in January 2007. The estimated population reduction is larger than the actual known removal. However, the above explanation for the apparent overestimate in December 2006 also explains the overestimate of this reduction. In addition, it is possible that some mortality, especially of young, occurred during the 4-month period between the surveys, adding to the known population reduction caused by the removal operation. Any such natural mortality would bring the actual and estimated reduction values closer to agreement.

## Conclusion

The double-count method for correcting visibility bias is theoretically biased to produce underestimates of true population size. This bias arises from the fact that not all horse groups are equally visible. The addition of sighting covariates to model differences in sighting probability among groups partially corrects for this bias, but unless these models are nearly perfect, undercounting is still possible. The results of this analysis, however, provide no indication that a negative bias is present. First, there is no indication of over-dispersion in the data. Over-dispersion is an expected consequence of non-independent observations. Second, the population model fits the estimates in light of the known removals quite well, which would not be the case if the population estimates were seriously biased. However, if some small bias remains, it would cause the population size to be underestimated, leading managers to remove fewer horses than they should, providing a conservative safety margin against removing too many animals.

Our results indicate that the ability of aerial observers to see horse groups is very strongly dependent on skill of the individual observer, size of the horse group, and vegetation cover. It is also more modestly dependent on the ruggedness of the terrain and the position of the sun. There is also some evidence that sighting conditions vary from one survey to the next. Finally, 100 percent sighting probability is only achieved for a few large horse groups. Thus, raw counts will almost always underestimate true population.

In conclusion, the integrated simultaneous double-count/sightability bias correction technique provided considerably more valid aerial population estimation results than the standard uncorrected aerial census method, and disclosed important variables that can affect the outcome of an aerial survey in this study area. The results were validated by known removals and realistic population growth rates, providing further support for the integrated technique and a better understanding of methodology for improving future aerial surveys of the Adobe Town and Salt Wells Creek Herd Management Areas.

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