INTRODUCTION

Wildlife (hunting) enterprises are important sources of revenue for property owners in New Mexico, and consequently elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) are vital economic resources for private landowners (Figure 1). Sustainable management of these resources requires accurate monitoring of populations. This is particularly true in arid habitats where annual changes in population productivity, and thus sustainable harvest and trophy quality, can be pronounced (Heffelfinger et al., 2003; Bender, 2011).

Many methods have been used to monitor the status, composition, and trends of deer and elk populations. Methods range from trend indices, which provide information on whether a population is increasing, stable, or declining, to abundance estimators, which provide a population estimate (Lancia et al., 1996). Population estimates are preferable to trend estimators for several reasons. First, they allow direct calculation of harvestable surplus. Population estimates can also be converted to densities, and relationships between resource availability (forage, etc.) and population size can be determined. Ultimately, it is the per capita resource (food, water) availability that determines individual body condition and thus population productivity, harvestable surplus, and animal (trophy) quality (Bender, 2011).

The most common trend indices used by landowners include minimum counts, spotlight or ground counts, and pellet group surveys. Unfortunately, most of these commonly used trend indices have many assumptions that usually result in trend information of uncertain value, and very few have been calibrated to actual population size (Keegan et al., 2011). Consequently, these methods are seldom used by management agencies to monitor populations because of the inherent problems and inaccuracies in these methods. For population estimates, the most commonly used and probably best method is an aerial sight-bias (sightability) model (Samuel et al., 1987; Otten et al., 1993). Sightability model surveys can be expensive to conduct because they require the use of a helicopter (Figure 2), but

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Sightability models estimate population size by correcting the number of observed elk or deer groups by the numbers missed due to incomplete detectability. Detectability is never complete because some animals are obscured by shadow, in vegetation, or otherwise hidden from view (Figure 3), and are thus missed during survey flights (Samuel et al., 1987). Many factors have been shown to affect detectability (Figures 4A and 4B), most commonly group size, activity (whether individuals are bedded, standing, moving), amount and type of vegetative cover, topography, and presence or absence of snow cover (Caughley, 1974; Otten et al., 1993; Unsworth et al., 1994; Anderson et al., 1998; Cogan and Diefenbach, 1998). Sightability models develop correction factors for variables that significantly influence detectability for a particular species in a particular habitat (Samuel et al., 1987; Unsworth et al., 1994).

Sightability models for elk and mule deer have been developed specifically for New Mexico habitats (L. Bender, unpublished data). Detectability of mule deer and elk during helicopter surveys in
Figures 4A and 4B. Many variables can potentially influence the likelihood of detecting a group of animals during surveys, including presence or absence of snow (top). In New Mexico, detection was driven solely or mostly by group size. Larger groups like these elk were more easily detected during surveys regardless of snow or vegetation cover (bottom). Photo courtesy of E. Watters.
stant proportion of the population was consistently seen among surveys) or minimum counts should not be used for management because detectability of elk and mule deer is not constant nor complete, but varies based upon animal behavior (grouping patterns and activity). Thus, minimum counts and ratios are likely to be inaccurate if not corrected for factors that influence detection of groups.

Sightability models are developed by modeling factors associated with groups seen during surveys versus groups missed. Once developed, sightability models work by predicting the sighting probability (Y) of all mule deer or elk groups encountered, where $Y = \frac{e^U}{1 + e^U}$ and $U = a$ linear model combining variables influencing group detectability (Hosmer and Lemeshow, 1989). Sightability correction factors (SCF) for each group seen are then developed using $SCF = 1 / Y$, and the resulting SCF is applied to each group counted during surveys (see discussion in Estimating Population Size section). The following describes the variables that influenced detection of mule deer and elk groups during surveys in New Mexico and the models that best correct for incomplete detection of individuals. Following this is a walk-through example of how this modeling works for estimating the corrected population size and ratios for mule deer and elk in New Mexico.

**MULE DEER**

The best supported sightability model for New Mexico corrected for both group size and level of activity:

$$U = -1.773 + (0.3249 \times G) + (0.7689 \times A)$$

where $G$ is the group size and $A$ is a class variable for mule deer activity at the time of observation (when the deer group was first seen from the helicopter) and is coded 1 for moving deer and -1 for standing or bedded deer. Positive coefficients for both group size and increasing activity indicate that detectability of mule deer increases as both group size and degree of movement increase. Sighting probabilities of mule deer groups plateau at $> 0.99$ when group size reaches 22, regardless of group activity. For group sizes of 1 to 25, sighting probabilities vary with both group size and activity,
with group size having a proportionately greater effect. During surveys, sighting probabilities for a lone mule deer are approximately 0.10 if bedded/standing and 0.34 if moving. If the group size of mule deer was 10, sighting probabilities increase to approximately 0.67 and 0.90 for bedded/standing and moving, respectively. Because mule deer groups are largest in winter, surveys can maximize detectability of mule deer, and thus numbers counted and precision of population estimates (by minimizing sighting error), by conducting mule deer surveys in winter when group sizes are largest. This model fit the observed data well and correctly predicted 82% of sighting outcomes.

The Mule Deer Sightability Model was developed in varied habitats of north-central (short grassland, piñon-juniper, oakbrush, ponderosa pine, and montane conifer habitats) and east-central (short grassland, piñon-juniper) New Mexico. The model is conservative (i.e., the selected model produces the lowest population estimate among the suite of statistically similar models) in areas with high canopy closure of piñon-juniper or montane conifer forest. For more open habitats, the model is relatively unbiased.

**ELK**

The best sightability model for elk corrected for group size only:

\[
U = -1.9520 + (0.3546 \times G)
\]

where G is the group size. Probability of sighting elk groups increases as group size increases until probability of sighting is > 0.99 at a group size of approximately 19. This is true regardless of vegetation type, activity, or other variables that affect sighting of elk during surveys. This model similarly fit the observed data well and correctly predicted 87% of sighting outcomes. The Elk Sightability Model was developed in the varied habitats of north-central (sage-steppe, aspen, piñon-juniper, ponderosa pine, montane conifer, montane meadow), northwest (desert scrub, aspen, piñon-juniper, montane conifer), and south-central (desert scrub, oakbrush, piñon-juniper, aspen, ponderosa pine, montane conifer) New Mexico. Like the Mule Deer Sightability Model, the Elk Sightability Model will be conservative in areas with high canopy closure of piñon-juniper or montane conifer forest.

**CONDUCTING SURVEYS**

Sightability surveys should ideally be flown using a Bell 206B JetRanger or 206L LongRanger helicopter with a pilot and at least 2 observers, although similar 4 seat helicopters (e.g., Hughes/MD 500, Robinson R44, etc.) likely will not significantly affect model predictions. The lead observer of the survey crew should be located in the front seat beside the pilot, and the secondary observer should be immediately behind the lead observer in the back seat. Surveys can be conducted with or without doors, although without doors greatly enhances comfort during surveys in warmer months.

For total population estimates, survey flights should be flown at 35 to 43 knots and approximately 100 to 150 ft (30–46 m) above ground level. Transect widths should be approximately 0.25 miles (0.40 km). Surveys can be conducted throughout the day, and are generally flown along north—south transects to minimize sun effects on the pilot and lead observer. A GPS track log is extremely helpful to ensure complete coverage of the survey unit.

When located, mule deer and elk groups should be circled and counted, with the following group characteristics recorded for each group.

**Mule deer**

- Group size.

- Group composition, including numbers of bucks, does, and fawns. Bucks should further be segregated by number of antler points or a subjective yearling, young (raghorn), or mature buck classification. At a minimum, yearlings and older bucks should be distinguished to help differentiate mortality rates and male age structure (Bender, 2006, 2011).

- Activity of the first mule deer observed in the group (the one that caught your attention when you first sighted the group), classed as either bedded, standing, or moving.
Table 1. Example of Spreadsheet for Calculating Sightability-Corrected Estimates of Mule Deer Population Size and Herd Composition Ratios Sightability Model for MULE DEER Observed During Aerial Sightability Surveys

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Totals: 10 6 2 2 1 0 1 1 Corrected total 27 16 7 5 3 0 2

Uncorrected ratios: F:D 0.33 Corrected ratios: F:D 0.45
B:D 0.33 B:D 0.30
% Y 0.50 % Y 0.63

*ACT = activity level; 1 = moving, -1 = standing/bedded.
Elk

- Group size.

- Group composition, including numbers of bulls, cows, and calves. Bulls should further be segregated by number of antler points or a subjective yearling, young (raghorn), or mature bull classification.

If you are only doing herd composition counts (rather than attempting a population estimate), groups of elk or deer counted should still be corrected for sightability, but flights do not have to follow the 0.25-mile transect grids outlined previously.

ESTIMATING POPULATION SIZE

The following is a simple example of applying the New Mexico Mule Deer Sightability Model to survey data. After completing a survey of the entire ranch, a manager observed 3 groups of mule deer (Table 1) and estimated the population size by using the Mule Deer Sightability Model (available as an Excel spreadsheet at the Corona Range and Livestock Research Center’s website at http://coronasc.nmsu.edu/documents/sightability-models_elk-and-mule-deer.zip). The following shows how the groups of deer are corrected for missed by the sightability model.

The first 3 groups observed in a mule deer survey consisted of 1 running yearling buck (Group 1), 5 standing deer (3 does and 2 fawns; Group 2), and 4 running deer (3 does and 1 mature buck; Group 3). Applying the sightability model $(U = -1.773 + [0.3249 \times G] + [0.7689 \times A])$ results in:

Group 1:
$U = -1.773 + (0.3249 \times 1) + (0.7689 \times 1) = -0.6792$

Group 2:
$U = -1.773 + (0.3249 \times 5) + (0.7689 \times -1) = -0.9174$

Group 3:
$U = -1.773 + (0.3249 \times 4) + (0.7689 \times 1) = 0.2955$

The probability of sighting each group $(Y)$ is then calculated:

Group 1:
$Y = e^{0.6782} / 1 + e^{0.6782} = 0.336$

Group 2:
$Y = e^{0.9174} / 1 + e^{0.9174} = 0.285$

Group 3:
$Y = e^{0.2955} / 1 + e^{0.2955} = 0.573$

Sighting correction factors (SCF) for each group are then calculated:

Group 1:
$SCF = 1 / Y = 1 / 0.336 = 2.98$

Group 2:
$SCF = 1 / Y = 1 / 0.285 = 3.51$

Group 3:
$SCF = 1 / Y = 1 / 0.573 = 1.75$

The observed deer groups are then corrected for missed groups based on the probabilities of detecting a group with those group size and activity characteristics:

Group 1:
$1 \times 2.98 = 2.98$

Group 2:
$5 \times 3.51 = 17.51$

Group 3:
$4 \times 1.75 = 7.00$

The final population size is estimated by summing all corrected group sizes:

$n = Group 1 + Group 2 + Group 3 = 3 + 18 + 7 = 28$

In this simple example, the original (uncorrected) survey counted only 10 deer in the 3 groups observed. Because detection of deer during surveys is not 100%, but rather varies with differing group
sizes and levels of activity, the corrected total was 28 deer; the survey missed about 18 deer based on the characteristics of groups seen. Thus, if the observed count was used, managers would have greatly underestimated the number of deer on the ranch. Consequently, management decisions based on deer density, such as amount of forage needed or how much to feed if supplementing the deer population, would also have been greatly underestimated. The result could have been much lower animal quality because resources per individual deer would have been overestimated from the observed count, or a much lower sustainable harvest than was actually available from the population.

Finally, this simple example covered only population size. As shown in Table 1, herd composition ratios would also have been biased using the observed count data. In this example, numbers of bucks would be overestimated (corrected buck: doe ratio = 30:100; uncorrected = 33:100) using the uncorrected observed count data, and the age structure of the bucks would be overestimated (i.e., there were actually proportionally fewer mature bucks than the count data indicated; corrected percent yearling bucks = 63%; uncorrected = 50%). Remember, ratio data, such as male:female, young:female, and age structure data, can provide managers with key information on their populations, including mortality rates and maximum sustainable harvests (Bender, 2006, 2011).

As noted previously, to aid in these calculations, a spreadsheet for estimating numbers of mule deer and elk using the New Mexico Mule Deer and Elk Sightability Models is available on New Mexico State University’s Corona Range and Livestock Research Center’s website (http://coronasc.nmsu.edu/documents/sightability-models_elk-and-mule-deer.zip) by following the “For Wildlife Managers” then “Mule Deer” links.

SOME GENERAL CONSIDERATIONS FOR SURVEYS
A good survey depends upon good observers, weather (low wind, ideally slightly overcast skies, etc.), and a good pilot. Given these, the following are some further considerations.
• Surveys should cover the entire ranch. Although subdividing the range into survey units (quadrats) and random sampling within quadrats could reduce flight time and survey expense, the variance associated with sampling error greatly increases the uncertainty in estimates and thus often lowers the precision associated with population estimates below levels needed for accurate management.

• Surveys should be conducted when group sizes are largest in order to increase numbers counted and counteract any potential problems associated with small group size correction factors (this is particularly true for bedded mule deer). This generally occurs in the winter, when deer and elk are either concentrated on winter ranges or more closely associated with water in desert habitats. Conducting surveys during this time results in higher sighting probabilities and thus less error associated with model estimates.

SOME COMMENTS ON STATISTICAL ERROR IN ESTIMATES
Estimates of population sizes and herd composition ratios are just that—estimates. Therefore, they contain error, which is usually fairly minimal if the entire ranch is surveyed, but can be significant if ranches are divided into quadrats and subsampled. Because error in estimates can be difficult to understand, most managers will (and should) treat the mean estimates from the model as a population index and recognize that there is error in the estimates; thus, they are best treated as relative values rather than absolute. In other words, the population estimate of 28 mule deer in the previous example should be viewed as “about 28 or so,” or maybe “25 to 30,” and the uncertainty in the value should be considered when making management plans.

The exact error in estimates can be calculated if managers desire (see Cogan and Diefenbach [1998] and Bender and Spencer [1999] for the best methods to do this). Three types of error occur in sightability estimates: (1) detectability (visibility) error due to differences in animal detectability (this is what the sightability models try to directly address), (2) model error due to error in regression model (U) estimates, and (3) sampling error due to non-uniform distribution of animals on the landscape. If a population is sampled rather than doing a complete count, meaning that only a portion of the
range/ranch is surveyed and results are extrapolated to the remainder of the area, sampling error contributes the most variance to population estimates (approximately 75–80%), followed by detectability error (15–20%) and model error (<5%; Otten et al., 1993). Alternatively, if the entire area is surveyed, then detectability error contributes the greatest variation to estimates (approximately 90%), followed by model error (approximately 10%; Cogan and Diefenbach, 1998).

Detectability error occurs due to differing visibility among individuals/groups, resulting in some being seen during surveys and others missed (Steinhorst and Samuel, 1989). Because correction factors for missed groups used in sightability models are estimates and not absolute values, this introduces some error into the population estimates. Detectability error can also include counting errors, such as misclassifying animals, undercounting, or overcounting groups (Cogan and Diefenbach, 1998). Most commonly, counting error involves undercounting groups, which introduces a negative bias into sightability models (Cogan and Diefenbach, 1998). As noted previously, detectability error can be minimized by conducting surveys when social group sizes are largest and use of open habitats greatest.

Model error is the variation in the regression predictions of group sizes (Steinhorst and Samuel, 1989). Correction coefficients for variables affecting detectability each have associated error, and thus each detectability-adjusted estimate of group size is precisely that—an estimate, not a point value. The magnitude of model error depends upon the variability in data used to develop the sightability model, sample sizes used to develop the model, and number of variables included in the model. Typically, models with few variables built on larger sample sizes minimize model error (Wong, 1996). Model error is usually negligible compared to detectability and sampling error.

Sampling error is generally the largest error component in sightability models. Sampling error occurs because of a lack of uniformity in the spatial distribution of animals, i.e., the uneven distribution of animals within and among sampling units (Steinhorst and Samuel, 1989). Often, not all sampling units are flown; rather, a subset (often stratified by expected density of elk or deer into strata of high, medium, and low density) is randomly selected and surveyed. The results of these are then extrapolated to all high-, medium-, and low-density strata for a total population estimate. The variation in estimates among surveyed units within a stratum is the sampling error. Because elk and deer are never uniformly distributed across a landscape, differences in numbers among sampling units can contribute significant error to sightability model predictions. Usually, more error is associated with lower-density strata due to patchy, infrequent occurrence of individuals within these strata. Thus, optimal allocation is usually employed for determining numbers of sample units in each stratum needing to be surveyed (Otten et al., 1993). Optimal allocation involves looking at or estimating sampling error within each stratum relative to numbers of deer seen in each stratum, then determining a proportional sampling effort that minimizes total error across strata in the final survey result. For most wildlife enterprises, the best option to minimize error in population estimates is to eliminate sampling error completely by surveying the entire ranch. This results in only detectability and model error being present in estimates, both of which are usually minor, particularly given that the New Mexico Mule Deer and Elk Sightability Models use few predictor variables and were built from relatively large samples. Therefore, it is highly recommended that managers survey their entire ranch.

However, if the ranch is only sampled, then randomization (bootstrap) methods, in preference to normalized variance estimators, should be used to generate comparative confidence intervals for sightability model estimates (Cogan and Diefenbach, 1998; Bender and Spencer, 1999). This will allow better accounting for amount and distribution of error in population estimates (Cogan and Diefenbach, 1998; Bender and Spencer, 1999) from all sources, especially detectability and sampling error.

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LITERATURE CITED

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