**Analysis of 2007-2014 Ouray Deer and Elk Survey Data**

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**Background**

Ouray National Wildlife Refuge (NWR) in Randlett, Utah, collected mule deer (*Odocoileus hemionus*) and elk (*Cervus elaphus*) population survey data during the winter (February – April), summer (July - September), and fall (November) seasons of 2007 – 2014. Surveys were conducted by vehicle on seven distinct fixed-length transects (Table 1), during which observers recorded all detections of deer or elk groups (hereafter clusters, where a cluster consists of ≥1 individual) along either side of the transect. Among the data recorded were species; total number of individuals in the cluster; the numbers of females, males, and young observable within the cluster; the distance to the centroid of the cluster (collected in a manner allowing computation of the perpendicular distance from the transect to the centroid); the management unit, and the habitat class.

 The primary objective of the Ouray survey was to use Distance methods (Buckland et al. 1993) to estimate deer and elk densities for the sampled populations, by season, over the eight years the survey was conducted so as to evaluate trends or patterns. Because all transects were placed on roads, which were not randomly distributed across the refuge, and because transects were not randomly placed on roads, density estimates from the surveys only pertain to the transects sampled. Previous attempts at placing transects on the Refuge more appropriately to allow broader interpretation of the results were unsuccessful due to weather and road access, as well as to ungulate behavior. Therefore, the density estimates are a weighted average (where weight is the product of transect length and effective strip width, the latter estimated using Distance methods) across all of the sampled transects.

Secondary objectives of the Ouray survey were to use the data to estimate age and sex ratios for deer and elk, and to use the results of the Distance analysis to evaluate the statistical power of the survey, in its current form, to detect trends over a 5 – 7 year timeframe.

**Analytical Methods**

*Density Estimation*

 I used Distance software version 6.2 (http://distancesampling.org/Distance/old-versions/distance62download.html) to model and estimate density and measures of precision for the Ouray survey data. I structured the data in Distance in a manner such that the years 2007 – 2014 were considered strata, and introduced covariates for species (deer, elk) and season (winter, summer, fall) to facilitate filtering data for separate species × season analyses. Because each of the seven transects were of differing length, and because during winter 2012 – 2014 replicate transects were run, for transect length I entered the product (length × replicates). Doing this allows Distance to properly handle transects sampled more than once during a particular season.

 My general approach to modeling, for all density analyses, was to first filter the data for the species × season(s) combination of interest, then specify four default detection function models (key function + series expansion): Half-normal + cosine, Half-normal + polynomial, Hazard-rate + cosine, Hazard-rate + polynomial. Because data for most species × season(s) × year combinations were too sparse to adequately estimate detection functions, I pooled data across years (i.e., strata) to estimate the detection function and expected cluster size, but specified to the software to estimate encounter rate and density by year. A consequence of this pooling is that density estimates across years are not statistically independent.

 The Distance software allows for multiple options with respect to settings for various components used in density estimation. I let Distance decide the number of adjustment terms to include for the series expansion for the detection function model, using the AIC statistic to select the best number of terms; I used the size biased regression method to estimate expected cluster size at distance *x*; I did not use multipliers to adjust the density estimates (they were not needed); and I estimated variances empirically. Initially I specified bootstrap variance estimates, but software warnings such as “failure to converge” and “probabilities greater than 1,” likely due to small sample size, suggested that bootstrapping was inappropriate for this dataset. Consequently, I used empirical variance estimates.

 Once I ran the default detection function models listed above on the data, I scrutinized the top ranked model (based on the AIC values) and examined goodness-of-fit (GOF) of the model to the data using the various default diagnostic procedures in Distance. In particular, I looked at the Chi-square statistics on the right tail of the detection function to see if right truncation was something that might improve fit. In cases where it looked like it might (and this is somewhat subjective), I right truncated the distance data (where there seemed to be the most lack of fit) to evaluate whether truncation improved fit or not. In cases where it did based on the GOF diagnostics, I re-ran the set of default detection function models on the truncated data, then used the best ranked model for inference.

 Once I completed the species × season analyses for winter, summer, and fall, there was some question as to whether pooling the data from winter and fall, or pooling data from winter, summer and fall might improve precision of the density estimates. For these pooled analyses I used the same general approach to modeling described above, but in addition I generalized the models to use season as a covariate for the detection function and used AIC to compare the covariate model to the constrained model with no covariates. I used the best model, based on AIC, for inference.

*Age and Sex Ratios*

 For each species × season × year combination I subsetted the data set to retain only those observations in which: (total number of individuals in the cluster) = (the numbers of females + males + young observed within the cluster). I then computed the proportion (*p*) of females (F) to adults (i.e., female + male = F + M) as *p* = F/(F + M), and the proportion of juveniles (J) to females as *p* = J/F. I computed those same proportions after pooling the data across years. In addition, I pooled counts from the summer and fall of year *t* and winter of year *t* + 1 and re-computed the female and juvenile proportions. Where standard errors are reported, I assumed *p* was binomial and computed the standard error as $\sqrt{p(1-p)/n}$, where *n* is the number of individuals in the denominator of the proportion.

 Finally, the relation between juvenile counts in year *t* to density in year *t* + 1 was plotted to assess the contribution of juveniles to adult density the following year.

*Power Analyses*

 I constructed Monte Carlo simulations to assess the power of the current Ouray survey method to detect density changes under various hypothetical scenarios. I chose to parameterize the simulations using data from deer during the winter season because those data represent a “best case scenario” for the success of the survey method currently in use. Specifically, there were more clusters detected (i.e., data) for deer during the winter than for any other species × season combination. Thus, we can be almost certain that the Ouray survey method will have less power for any other species × season combination.

 The quantity of interest in the simulations I constructed is the power to detect change in density over some period of time, when in fact a decline has actually occurred. In other words, power is the probability of rejecting the null hypothesis of no change in density, when in fact density has changed. A power of 0 means a true change in density is never detected, whereas a power of 1 means a true change in density is always detected. For simplicity, I used a linear model of density (*d*) decline over time (*t*) with a stochastic element (ε) estimated from the survey data: *d* = *β*0 + *β*1*t* + ε, where *β*0 is an arbitrary initial or starting density (I let *β*0  = 0.014416, because it was the maximum density estimated for deer in the winter), and *β*1 is a slope parameter representing the change in density per unit time. In short, this model computes the expected density at *t*, and adds a stochastic component ε that reflects the variability inherent in the Ouray survey data. For these simulations I assumed ε ~ *N*(0, $s\_{\hat{d}}^{2}$), where $s\_{\hat{d}}^{2}$ is the sum of population (i.e., temporal) variation and sampling error: $s\_{\hat{d}}^{2}$ = $s\_{d}^{2}$ + var($\hat{d}\_{t}$). I estimated $s\_{\hat{d}}^{2}$ empirically from the winter deer density estimates using the sample variance formula (Skalski and Robson 1992): $s^{2}= \frac{\sum\_{i=1}^{n}\left(d\_{i}-\overbar{d}\right)^{2}}{n-1}$, which yielded the value 0.000010866.

 For these power simulations I investigated both a 20% and 50% decline in the population over the survey period (*T*), where *T* = 5, 7, 10, 15, and 20 years. This resulted in 10 different scenarios, each of which I simulated 10,000 times to yield a total of 100,000 data sets. For each data set I analyzed the data using a standard linear regression model to estimate the slope parameter, and determined if the slope parameter was significantly different from 0 at α = 0.05, 0.10, and 0.20. I then tallied the proportion of the time there were significant differences, which gives an empirical estimate of power.

**Results**

*Density Estimation*

 Prior to 2011 all 7 transects were surveyed once per season, and the average number of deer clusters detected per year during the winter, summer and fall seasons of 2007-2010 were identical, with 5.0, 5.0, and 5.0 clusters, respectively. After 2011, the 7 transects were surveyed five times each during the winter, but still only once during the summer and fall seasons. The average number of deer clusters detected per year during the winter, summer and fall seasons of 2012 – 2014 were 17.7, 5.0, and 5.0 clusters, respectively. Clearly, the replicate surveys conducted during the winters of 2012 – 2014 substantially increased the average number of clusters detected per year.

 I was able to estimate deer density (numbers/ha) and associated measures of precision for all year × season combinations, except the fall of 2011 when surveys were not run (Figure 1, Appendix 1). Because data were pooled across years to estimate the detection function, the detection probability within a season remained constant across years but varied across seasons. For winter, summer and fall, the estimated detection probabilities (standard error) were 0.199 (0.0204), 0.149 (0.0391) and 0.270 (0.0762), respectively.

 As measured by the average coefficient of variation (CV) across all years (2007 – 2014), data quality for deer was greatest during the winter (CV = 59.3%), intermediate during the fall (CV = 79.7%), and lowest during the summer (CV = 86.8%). However, when we consider only the data from 2007 – 2010, when transects were surveyed only once during the winter, summer and fall, the average CVs are comparable at 74.0%, 80.1% and 73.5%, respectively. During the winter of the years 2012 – 2014 the replicate surveys substantially increased precision, the average CV dropped from 74.0% (pre-2011) to 40.7%. As expected, pooling data across seasons substantially improved the precision of estimates. When winter and fall data were pooled the average CV from 2007 – 2014 was 41.1%, and when data from all seasons were pooled the average CV from 2007 – 2014 was 32.0%.

The average number of elk clusters detected per year during the winter and summer of 2007-2010 were 2.5 and 4.3, whereas during the winter and summer seasons of 2012 – 2014 (i.e., replicate winter surveys) the average number of clusters detected per year were 5.0 and 2.3.

 I was able to estimate elk density (numbers/ha) and associated measures of precision for only the winter and summer seasons, and for each season there was one year with insufficient data for estimation (Figure 2, Appendix 2). There were insufficient data to estimate elk density during the fall. However, for winter and summer the estimated detection probabilities (standard error) were 0.185 (0.0463) and 0.223 (0.0352), respectively.

As measured by the average CV across all years (2007 – 2014), data quality for elk was greatest during the winter (average CV = 83.8%) and lowest during the summer (average CV = 90.9%). However, when we consider only the data from 2008 – 2010, when transects were surveyed only once during the winter and summer, the average CVs are comparable at 91.9% and 87.7%. During the winter of the years 2012 – 2014, when replicate surveys were run, precision substantially increased and the average CV dropped from 91.9% (pre-2011) to 72.2%. As expected, pooling data across seasons substantially improved the precision of estimates. When winter and summer data were pooled the average CV was 63.8%.

 For both deer and elk there was a positive association between the standard error of density, and density itself; larger density estimates were less precise (i.e., had larger standard errors; Figure 3).

 Effective strip width (ESW) is calculated and output by Distance each time a detection function is estimated. In the Ouray analyses ESW was output for each species × season combination for which density estimates were possible (Table 2). However, because it was necessary to pool data across years to estimate the detection function, the ESW reported by Distance is constant across years.

ESW can be used to compute the effective sampling area for a transect. To do this, convert the transect length to the same units in which ESW is reported (in these analyses the units were meters), then multiply transect length by 2 \* ESW to get the effective sampling area in square-meters. It is necessary to multiply ESW by 2 because one strip occurs on each side of the transect. To convert to hectares, divide this product by 10,000. As an example, the length of transect 0 is 0.4358 km, or 435.8 m. For deer during the winter survey ESW was 177.9 meters (Table 2). Therefore, to compute the effective area sampled for deer on transect 0 during the winter, one would evaluate the expression 435.8\*(2\*177.9)/10000 to get an effective sampling area of 15.1 ha.

*Age and Sex Ratios*

 As noted in the methods, the only data included in this analysis were clusters in which every individual in the cluster could be classified into an age and sex class. As a result, for deer in the winter, summer, and fall there were 195, 72, and 81 individuals, respectively, classified into an age and sex class (Table 3A, Appendix 3A). For elk in the winter, summer, and fall there were 171, 299, and 4 individuals, respectively, classified into an age and sex class (Table 3B, Appendix 3B). For deer, on average, the proportion of females to adults and juveniles to females was greatest in the winter and lowest in the summer. For elk, on average, the proportion of females to adults was greatest in both the winter and summer, and the proportion of juveniles to females was greatest in the winter.

 For deer counts pooled over the summer and fall of year *t* and winter of year *t* + 1, the number of individuals that could be classified into an age and sex class ranged from 14 to 153 (Table 4). The proportion of females to adults averaged 0.77 and did not vary much across years (Figure 4). The proportion of juveniles to females averaged 0.33 and started out high in 2007, rapidly dropped to very low levels, then beginning in 2011 it rapidly climbed and leveled off in 2013 (Figure 4). A plot of the juvenile deer counts in year *t*, where counts were formed by pooling the summer and fall data of year *t* with the winter data of year *t* + 1, against deer density pooled over the winter, summer and fall (i.e., the density estimates in Appendix 1.E), suggests a positive linear or positive curvilinear relation between the two (Figure 5). However, there is a great deal of variability in the data. The analyses reported in Table 4 and Figures 4 and 5 could not be performed for elk, as there were insufficient data.

*Power Analyses*

 Under the current survey methodology used at Ouray NWR, the power I estimated for detecting a 20% decline in density over a 5 – 7 year period was very low (Figure 6). As expected, when the 20% decline occurred over a longer survey period (e.g., 20 years) the power increased, but it was still only 0.26 at an α = 0.10. Even for a 50% decline in density over a 5 – 7 year period there was very low power, in the range of 0.35 – 0.44 (α = 0.10), though when the 50% decline occurred over 20 years the power was relatively high at 0.78 (α = 0.10).

**Discussion**

 For both deer and elk and there was no strong evidence that any particular season was better than any other for running surveys (though clearly fall surveys for elk are not effective, as too few elk are detected), at least from the standpoint of sample size (i.e., number of clusters detected), detection probabilities, or precision as measured by the CV on density. When considering only the data from 2007 – 2010, when survey effort was constant across seasons, for both deer and elk there was little variation in the average number of clusters detected or the CVs on density. The detection probability for deer in the fall was somewhat larger than for winter and summer, however the precision on that estimate was poor and a 95% confidence interval on the estimate covers the point estimates for the other seasons, so there’s no strong evidence that fall was better for surveying. For elk, detection probabilities in the winter and summer did not differ substantially.

 Several lines of evidence for deer and elk indicated replication of surveys on transects, as was done during the winters of 2012 – 2014, is an effective way to improve the survey data. For both species there was evidence of an increase in the average number of clusters detected, and a decrease in the CVs on density. This pattern was reinforced by the results for seasons that were pooled. Pooling seasons has the effect of increasing the quantity of data (i.e., the number of clusters) for estimation, and for both deer and elk pooling across seasons substantially decreased the CVs on density. Of course, the downside of pooling across seasons is that the resulting density estimate is a weighted average across the seasons that were pooled, so there is little to no information useful for management. Thus, if survey data need to be improved (with respect to precision) it would be better to increase replication within a season rather than pool across seasons.

 A useful feature of the Distance software I used for analysis is that it reports the percent contribution of certain variance components, specifically detection probability, encounter rate, and cluster size, to the variance of the density estimate. In the analysis I did a recurrent pattern that emerged was that encounter rate was the largest contributor to the imprecision in the density estimate. To give an example, for deer during the winter season the average percent contribution of detection probability, encounter rate, and cluster size to the overall variance on density was 4.0%, 89.5%, and 6.5%, respectively. Clearly if there’s a desire to improve the precision of the density estimates, then the bulk of the effort should be put into increasing the encounter rate (recall, this result includes the replicate surveys during the winter of 2012 – 2014, so the results would be even worse for the other seasons). The best way to do that is to replicate surveys as much as possible. It might be possible too to increase encounter rates by surveying at times when movement of animals (e.g., morning or evening) and visibility of clusters (e.g., after a snowfall) are at their peak.

 The results of the power analyses showed that, as currently configured, the deer and elk surveys being conducted have very low power to detect a 20% decline in the population over a 5 – 7 year timeframe. Collecting several more years of data would improve the power to detect declines, but even at 20 years the power is quite low. Power for detecting a 50% decline is much better under the current survey configuration, but a long timeframe (e.g., 15 – 20 years) is needed to get decent power.

Although the power of the data using Distance to detect population trends over the 5-7 year timeframe was higher for deer than for elk, these results suggest that current survey methods have insufficient power for most management purposes. If estimation of cervid resources at Ouray NWR is important for Refuge management purposes, then replicate surveys within the winter season appear to be the most effective means to increase encounter rates, thus improving power. If increased replication of surveys is not feasible and there is still a desire to monitor trends in density, then it might be necessary to consider alternative methods for estimating density, or consider estimating some other parameter (not an index) that provides the necessary information but is more easily and precisely estimated.

**Literature cited**

Buckland, S.T., Anderson, D.R., Burnham, K.P. and Laake, J.L. 1993. *Distance Sampling: Estimating Abundance of Biological Populations.* Chapman and Hall, London. 446pp.

Skalski, J. R., and D. S. Robson. 1992. Techniques for wildlife investigations: Design and analysis of capture data. Academic Press. 237 pp.

Table 1. Survey transect lengths, Ouray NWR.

|  |  |
| --- | --- |
|   |   |
| Transect | Length (km) |
| 0 | 0.436 |
| 1 | 13.476 |
| 2 | 3.979 |
| 3 | 0.340 |
| 4 | 19.311 |
| 5 | 1.865 |
| 6 | 1.124 |

Table 2. Effective strip width (ESW; meters) estimated by Distance for each species × season combination for which density estimates were possible. Because data were pooled across years to estimate the detection function, the ESW is constant across years.

|  |  |  |
| --- | --- | --- |
|   |   |   |
| Species | Season(s) | ESW (m) |
| Deer | winter | 177.94 |
|  | summer | 71.74 |
|  | fall | 115.27 |
|  | winter + fall | 166.92 |
|  | winter + summer +fall | 136.30 |
| Elk | winter | 184.50 |
|  | summer | 223.07 |
|   | winter + summer | 227.70 |

Table 3. Counts of females, males, juveniles and adults, and the proportion (and standard error) of females to adults (F/A) and the proportion (and standard error) of juveniles to females (J/F), for deer (A) and elk (B) at Ouray NWR.

A. Deer

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |   |   |   |   |
| Season | Total | Female | Male | Juv | Adult | F/A | se(F/A) | J/F | se(J/F) |
| winter | 195 | 116 | 17 | 62 | 133 | 0.872 | 0.029 | 0.534 | 0.046 |
| summer | 72 | 45 | 21 | 6 | 66 | 0.682 | 0.057 | 0.133 | 0.051 |
| fall | 81 | 48 | 19 | 14 | 67 | 0.716 | 0.055 | 0.292 | 0.066 |

B. Elk

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |   |   |   |   |
| Season | Total | Female | Male | Juv | Adult | F/A | se(F/A) | J/F | se(J/F) |
| winter | 171 | 87 | 33 | 51 | 120 | 0.725 | 0.041 | 0.586 | 0.053 |
| summer | 299 | 165 | 62 | 72 | 227 | 0.727 | 0.030 | 0.436 | 0.039 |
| fall | 4 | 1 | 3 | 0 | 4 | 0.250 | 0.217 | 0.000 | 0.000 |

Table 4. Pooled counts of female, male, juvenile and adult deer, where data were pooled over the summer and fall of year *t* and winter of year *t* + 1, and the proportion of females to adults (F/A) and juveniles to females (J/F) in Ouray NWR. There are no data for 2014 because that would require data from the winter of 2015 for pooling, which were not available.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |   |   |
| Year | Total | Female | Male | Juv | Adult | F/A | J/F |
| 2007 | 32 | 17 | 4 | 11 | 21 | 0.81 | 0.65 |
| 2008 | 14 | 10 | 2 | 2 | 12 | 0.83 | 0.20 |
| 2009 | 31 | 27 | 2 | 2 | 29 | 0.93 | 0.07 |
| 2010 | 23 | 17 | 5 | 1 | 22 | 0.77 | 0.06 |
| 2011 | 25 | 12 | 9 | 4 | 21 | 0.57 | 0.33 |
| 2012 | 153 | 91 | 15 | 47 | 106 | 0.86 | 0.52 |
| 2013 | 58 | 28 | 16 | 14 | 44 | 0.64 | 0.50 |
| 2014 |   |   |   |   |   |   |   |

Figure 1. Estimated annual deer density (95% CI) at Ouray NWR during the winter, summer, and fall, as well as for data pooled over winter and fall, and pooled over winter, summer, and fall. No survey data were collected during the fall of 2011.

Figure 2. Estimated annual elk density (95% CI) at Ouray NWR during the winter and summer, as well as for data pooled over winter and summer. There were insufficient data to estimate density during the winter 2007, summer 2014, and fall 2007 – 2014.

Figure 3. The precision of estimated winter deer density (A), and the precision of estimated winter elk density (B), for survey data collected from Ouray NWR.

A. Deer

B. Elk

Figure 4. Plots of the proportion of females to adults (F/A) and juveniles to females (J/F) in Ouray NWR, based on pooled counts of female, male, juvenile and adult deer, where data were pooled over the summer and fall of year *t* and winter of year *t* + 1. There are no data for 2014 because that would require data from the winter of 2015, which were not available.

Figure 5. Plot of the juvenile counts in year *t*, where counts were formed by pooling the summer and fall data of year *t* with the winter data of year *t* + 1, against deer density pooled over the winter, summer and fall (i.e., the density estimates in Appendix 1.E), for Ouray NWR.

Figure 6. Estimated power of the survey methodology used at Ouray NWR to detect a 20% decline (A) or a 50% decline (B) in density over survey periods of 5, 7, 10, 15, and 20 years.

A. 20% decline

B. 50% decline

Appendix 1. Deer density estimates, Ouray NWR.

A. Annual deer density (number/ha), winter.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.007690 | 0.004937 | 64.2 | 0.002281 | 0.025930 |
| 2008 | 0.004806 | 0.002850 | 59.3 | 0.001546 | 0.014942 |
| 2009 | 0.004806 | 0.003567 | 74.2 | 0.001217 | 0.018974 |
| 2010 | 0.001923 | 0.001891 | 98.4 | 0.000348 | 0.010627 |
| 2011 | 0.002884 | 0.001629 | 56.5 | 0.000943 | 0.008821 |
| 2012 | 0.002884 | 0.000949 | 32.9 | 0.001504 | 0.005528 |
| 2013 | 0.011947 | 0.005417 | 45.3 | 0.004917 | 0.029031 |
| 2014 | 0.007003 | 0.003072 | 43.9 | 0.002962 | 0.016558 |

B. Annual deer density (number/ha), summer.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.002097 | 0.001516 | 72.3 | 0.000554 | 0.007930 |
| 2008 | 0.005242 | 0.004058 | 77.4 | 0.001282 | 0.021440 |
| 2009 | 0.008387 | 0.006291 | 75.0 | 0.002127 | 0.033071 |
| 2010 | 0.005242 | 0.005015 | 95.7 | 0.000992 | 0.027702 |
| 2011 | 0.012580 | 0.007431 | 59.1 | 0.004031 | 0.039267 |
| 2012 | 0.001348 | 0.001468 | 108.9 | 0.000216 | 0.008405 |
| 2013 | 0.003145 | 0.003057 | 97.2 | 0.000583 | 0.016958 |
| 2014 | 0.002247 | 0.002446 | 108.9 | 0.000360 | 0.014008 |

C. Annual deer density (number/ha), fall (there were no fall 2011 data).

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| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.007016 | 0.004617 | 65.8 | 0.002070 | 0.023785 |
| 2008 | 0.004385 | 0.002888 | 65.9 | 0.001293 | 0.014876 |
| 2009 | 0.003508 | 0.003027 | 86.3 | 0.000758 | 0.016232 |
| 2010 | 0.002631 | 0.002006 | 76.3 | 0.000658 | 0.010513 |
| 2011 |  | No data collected |  |  |
| 2012 | 0.001504 | 0.001382 | 91.9 | 0.000301 | 0.007520 |
| 2013 | 0.002631 | 0.002103 | 79.9 | 0.000623 | 0.011106 |
| 2014 | 0.001504 | 0.001382 | 91.9 | 0.000301 | 0.007520 |

D. Annual deer density (number/ha), winter and fall data pooled (there were no fall 2011 data).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.014950 | 0.005759 | 38.5 | 0.006964 | 0.032097 |
| 2008 | 0.009344 | 0.003473 | 37.2 | 0.004467 | 0.019546 |
| 2009 | 0.008409 | 0.004271 | 50.8 | 0.003124 | 0.022634 |
| 2010 | 0.004672 | 0.002525 | 54.0 | 0.001639 | 0.013314 |
| 2011 | 0.002803 | 0.001563 | 55.8 | 0.000923 | 0.008509 |
| 2012 | 0.004405 | 0.001288 | 29.2 | 0.002460 | 0.007887 |
| 2013 | 0.014416 | 0.004519 | 31.4 | 0.007720 | 0.026920 |
| 2014 | 0.008409 | 0.002702 | 32.1 | 0.004434 | 0.015948 |

E. Annual deer density (number/ha), winter, fall, and summer data pooled (there were no fall 2011 data).

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.016378 | 0.005297 | 32.3 | 0.008575 | 0.031281 |
| 2008 | 0.013649 | 0.003429 | 25.1 | 0.008256 | 0.022565 |
| 2009 | 0.015468 | 0.005524 | 35.7 | 0.007585 | 0.031547 |
| 2010 | 0.009099 | 0.004207 | 46.2 | 0.003662 | 0.022610 |
| 2011 | 0.013649 | 0.005118 | 37.5 | 0.006332 | 0.029418 |
| 2012 | 0.005459 | 0.001568 | 28.7 | 0.003071 | 0.009705 |
| 2013 | 0.016768 | 0.003975 | 23.7 | 0.010439 | 0.026934 |
| 2014 | 0.010139 | 0.002676 | 26.4 | 0.005977 | 0.017200 |

Appendix 2. Elk density estimates, Ouray NWR. There were insufficient data to estimate density during the winter 2007, summer 2014, and fall 2007 – 2014.

A. Annual elk density (number/ha), winter.

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| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV(%) | 95% CI | 95% CI |
| 2007 | Insufficient | Data |  |  |
| 2008 | 0.003591 | 0.003550 | 98.9 | 0.000659 | 0.019554 |
| 2009 | 0.001197 | 0.001183 | 98.9 | 0.000220 | 0.006518 |
| 2010 | 0.004788 | 0.003736 | 78.0 | 0.001176 | 0.019499 |
| 2011 | 0.003591 | 0.003389 | 94.4 | 0.000672 | 0.019200 |
| 2012 | 0.003078 | 0.001975 | 64.2 | 0.000940 | 0.010079 |
| 2013 | 0.004104 | 0.002381 | 58.0 | 0.001389 | 0.012125 |
| 2014 | 0.000513 | 0.000485 | 94.5 | 0.000100 | 0.002637 |

B. Annual elk density (number/ha), summer.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.005686 | 0.006442 | 113.3 | 0.000880 | 0.036745 |
| 2008 | 0.014214 | 0.013446 | 94.6 | 0.002778 | 0.072740 |
| 2009 | 0.008529 | 0.007281 | 85.4 | 0.001892 | 0.038439 |
| 2010 | 0.011371 | 0.009456 | 83.2 | 0.002605 | 0.049648 |
| 2011 | 0.012793 | 0.009822 | 76.8 | 0.003146 | 0.052015 |
| 2012 | 0.006092 | 0.005553 | 91.2 | 0.001247 | 0.029763 |
| 2013 | 0.002437 | 0.002237 | 91.8 | 0.000494 | 0.012011 |
| 2014 |   | Insufficient Data |   |   |

C. Annual elk density (number/ha), winter and summer data pooled.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|   |   |   |   |   |   |
|  | Density | Standard |  | Lower | Upper |
| Year | Estimate | Error | CV (%) | 95% CI | 95% CI |
| 2007 | 0.003460 | 0.003744 | 108.2 | 0.000558 | 0.021434 |
| 2008 | 0.013838 | 0.008921 | 64.5 | 0.004138 | 0.046280 |
| 2009 | 0.006919 | 0.004281 | 61.9 | 0.002160 | 0.022165 |
| 2010 | 0.013838 | 0.006643 | 48.0 | 0.005504 | 0.034794 |
| 2011 | 0.012973 | 0.005976 | 46.1 | 0.005271 | 0.031929 |
| 2012 | 0.008155 | 0.004053 | 49.7 | 0.003145 | 0.021146 |
| 2013 | 0.007413 | 0.003054 | 41.2 | 0.003344 | 0.016434 |
| 2014 | 0.000741 | 0.000672 | 90.6 | 0.000150 | 0.003670 |

Appendix 3. Counts of females, males, juveniles and adults, and the proportion of females to adults (F/A) and the proportion of juveniles to females (J/F), for deer (A) and elk (B) in Ouray NWR. For elk some years are not reported because there were insufficient data.

A. Deer

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |   |   |   |   |   |   |
| Season | Year | Total | Female | Male | Juv | Adult | F/A | J/F |
| winter | 2007 | 1 | 1 | 0 | 0 | 1 | 1.00 | 0.00 |
|  | 2008 | 2 | 1 | 0 | 1 | 1 | 1.00 | 1.00 |
|  | 2009 | 3 | 1 | 0 | 2 | 1 | 1.00 | 2.00 |
|  | 2010 | 6 | 4 | 0 | 2 | 4 | 1.00 | 0.50 |
|  | 2011 | 11 | 10 | 0 | 1 | 10 | 1.00 | 0.10 |
|  | 2012 | 6 | 1 | 5 | 0 | 6 | 0.17 | 0.00 |
|  | 2013 | 138 | 85 | 6 | 47 | 91 | 0.93 | 0.55 |
|  | 2014 | 28 | 13 | 6 | 9 | 19 | 0.68 | 0.69 |
|  |  |  |  |  |  |  |  |  |
| summer | 2007 | 2 | 1 | 1 | 0 | 2 | 0.50 | 0.00 |
|  | 2008 | 8 | 7 | 1 | 0 | 8 | 0.88 | 0.00 |
|  | 2009 | 11 | 11 | 0 | 0 | 11 | 1.00 | 0.00 |
|  | 2010 | 8 | 5 | 3 | 0 | 8 | 0.63 | 0.00 |
|  | 2011 | 13 | 8 | 1 | 4 | 9 | 0.89 | 0.50 |
|  | 2012 | 6 | 2 | 4 | 0 | 6 | 0.33 | 0.00 |
|  | 2013 | 13 | 5 | 7 | 1 | 12 | 0.42 | 0.20 |
|  | 2014 | 11 | 6 | 4 | 1 | 10 | 0.60 | 0.17 |
|  |  |  |  |  |  |  |  |  |
| fall | 2007 | 28 | 15 | 3 | 10 | 18 | 0.83 | 0.67 |
|  | 2008 | 3 | 2 | 1 | 0 | 3 | 0.67 | 0.00 |
|  | 2009 | 14 | 12 | 2 | 0 | 14 | 0.86 | 0.00 |
|  | 2010 | 4 | 2 | 2 | 0 | 4 | 0.50 | 0.00 |
|  | 2012 | 6 | 3 | 3 | 0 | 6 | 0.50 | 0.00 |
|  | 2013 | 9 | 4 | 5 | 0 | 9 | 0.44 | 0.00 |
|   | 2014 | 17 | 10 | 3 | 4 | 13 | 0.77 | 0.40 |

B. Elk

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |   |   |   |   |   |   |
| Season | Year | Total | Female | Male | Juv | Adult | F/A | J/F |
| winter | 2008 | 2 | 1 | 0 | 1 | 1 | 1.00 | 1.00 |
|  | 2009 | 3 | 0 | 3 | 0 | 3 | 0.00 |  - |
|  | 2010 | 61 | 33 | 5 | 23 | 38 | 0.87 | 0.70 |
|  | 2011 | 50 | 21 | 15 | 14 | 36 | 0.58 | 0.67 |
|  | 2012 | 28 | 15 | 7 | 6 | 22 | 0.68 | 0.40 |
|  | 2013 | 25 | 17 | 1 | 7 | 18 | 0.94 | 0.41 |
|  | 2014 | 2 | 0 | 2 | 0 | 2 | 0.00 |  - |
|  |  |  |  |  |  |  |  |  |
| summer | 2007 | 19 | 5 | 13 | 1 | 18 | 0.28 | 0.20 |
|  | 2008 | 97 | 57 | 9 | 31 | 66 | 0.86 | 0.54 |
|  | 2009 | 10 | 7 | 1 | 2 | 8 | 0.88 | 0.29 |
|  | 2010 | 65 | 31 | 20 | 14 | 51 | 0.61 | 0.45 |
|  | 2011 | 44 | 31 | 7 | 6 | 38 | 0.82 | 0.19 |
|  | 2012 | 35 | 19 | 9 | 7 | 28 | 0.68 | 0.37 |
|  | 2013 | 29 | 15 | 3 | 11 | 18 | 0.83 | 0.73 |
|  |  |  |  |  |  |  |  |  |
| fall | 2007 | 1 | 1 | 0 | 0 | 1 | 1.00 | 0.00 |
|   | 2010 | 3 | 0 | 3 | 0 | 3 | 0.00 |  - |