COST-BENEFIT ANALYSIS OF A REDUCTION IN ELK BRUCELLOSIS SEROPREVALENCE IN THE SOUTHERN GREATER YELLOWSTONE AREA

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Executive Summary

Cattle producers and state wildlife management agencies have undertaken several brucellosis management strategies aimed at reducing the risk of bacterial transmission from elk to cattle grazing in the southern greater Yellowstone area. However, despite ongoing management efforts, cases of brucellosis continue to crop up in cattle and domestic bison in the GYA, and the wildlife-livestock brucellosis interface appears to be expanding. With decreasing budgets with which to combat brucellosis, a better understanding of the regional cost-effectiveness of available management strategies is necessary. This study is focused on the costs and benefits of management strategies aimed at reducing brucellosis seroprevalence in elk. Specifically, strategies that reduced elk to cattle transmission risk in different ways were evaluated: 1) test and slaughter of seropositive elk; 2) vaccination of elk with *Brucella abortus* strain 19; and 3) low-density feeding of elk.

Cattle producers in the southern greater Yellowstone area were surveyed with regard to whether elk were seen overlapping with their cattle in the winter months. The information garnered from this survey was used to create a resource selection function of elk and cattle overlap. A risk model was then created, which transformed the probability of elk and cattle overlap into the risk of *B. abortus* being transmitted from elk to cattle resulting in financial costs associated with cattle reactors being found. Management strategies were then modeled to effect varying reductions in elk seroprevalence, thus increasing the number of years until a spillover event was expected. The net change in the annualized cost of a brucellosis case was then compared to the annualized cost of the management strategy that increased the time period until an expected case.

Costs exceeded estimated benefits for all three elk management strategies evaluated. A society that is only willing to pay as much for a management strategy as its expected benefit should not invest in any wildlife management strategies aimed at elk seroprevalence reduction. However, if a society is willing to pay more for management than its expected benefit it may consider adopting one or more strategies. Low-density feeding of elk has the least-negative net benefit, and should therefore be the top strategy chosen. In general, investment in relatively inexpensive cattle management strategies may generate higher net benefits. These strategies may include hazing elk away from private cattle feedlines, fencing haystacks, and perhaps even adult-booster vaccination (if background risk is sufficiently high).

INTRODUCTION

Bovine brucellosis is a disease caused by the bacteria *Brucella abortus.* The disease affects wild and domestic ungulates, including elk (*Cervus elaphus*), bison (*Bison bison)*, cattle (*Bos taurus*), and humans. The Greater Yellowstone Area (GYA) is the only place in the United States where bovine brucellosis occurs in free-ranging wildlife populations. In the southern GYA, elk are supplementally fed during the winter months on 23 elk feedgrounds (Dean *et al.* 2004). On the elk feedgrounds, average seroprevalence for brucellosis (i.e., the proportion of animals with detectable antibodies to the bacteria, although not necessarily actively infected) averages approximately 22%. In non-feedground areas, seroprevalence averages 3.5% (Scurlock and Edwards 2010), but appears to be rising. It is suspected that private lands with limited hunting access in these areas are creating an environment similar to feedgrounds (Cross *et al.* 2010; Maichak *et al.* 2009).

Brucellosis in elk poses little human health risk; however, it does create a risk to cattle in the affected region. If cattle contract brucellosis, individual cattle producers and the region's livestock industry are financially impacted due to Federal and State regulations to control and eradicate the disease. Current policies require cattle herds with reactors to bovine brucellosis to be quarantined and/or depopulated.

Cattle producers implement a variety of brucellosis management and prevention strategies to reduce the risk of their herds contracting brucellosis and being depopulated or quarantined (Roberts *et al.* 2012). The most common management strategies include fencing haystacks, modifying winter-feeding practices, and allowing state wildlife agencies to haze elk off private property, all of which discourage elk from commingling with cattle during the period of high transmission risk (February-June). Cattle are also vaccinated with the RB51 vaccine, which provides protection against brucellosis-induced abortion in approximately 60% of animals (Poester *et al.* 2006). A small number of producers delay grazing on high-risk grazing allotments, particularly those that overlap with elk feedgrounds.

The Wyoming Game and Fish Department (WGFD) has undertaken several brucellosis management strategies targeted at elk. The pilot Test-and-Slaughter program (2006-2010) involved trapping elk on selected feedgrounds, testing them for antibodies against *B. abortus*, and culling seropositive females from the population. Tissue samples from culled elk were then collected and cultured in an attempt to determine whether seropositive individuals were actively infected with *B. abortus*. The program's goals were to improve methods of detecting and preventing infections in elk, offer insights for vaccine development, and attempt to reduce seroprevalence by removing potentially infected animals. The pilot program appears to have successfully reduced brucellosis seroprevalence in elk to as low as 5% on select feedgrounds (Scurlock and Edwards 2010); however, its social and economic costs are relatively high, raising questions about its suitability for use at a regional level or over a sustained period.

The WGFD also vaccinates elk calves on most feedgrounds with the *Brucella* strain 19 (S19) vaccine via biobullets (Dean *et al.* 2004). Since 1985, nearly 100,000 elk have been inoculated. However, efficacy of S19 in preventing abortions in elk is low (25%, Roffe *et al.* 2004), and reductions in brucellosis prevalence among elk attending vaccinated feedgrounds have not been observed (WGFD unpublished data).

Additionally, the WGFD has changed the spatial pattern of hay distribution on some feedgrounds from continuous lines to dispersed piles (to reduce elk-elk contact), and truncating feeding seasons on some feedgrounds to reduce the probability of an infectious abortion event occurring when elk are congregated on feedgrounds (Scurlock 2010). These practices may reduce the number of elk-fetus contacts by >70% (Creech *et al.* 2012). WGFD is also improving native winter habitat via controlled burns and other management techniques to improve elk winter range to reduce elk dependence on supplemental feed (Thorne 2001). Although the WGFD has recorded the amount of resources invested in these management strategies, the strategies' benefits have not been estimated because the extent to which lower elk seroprevalence reduces outbreaks in cattle is unknown.

Despite ongoing management efforts, cases of brucellosis continue to crop up in cattle and domestic bison in the GYA, and the wildlife-livestock brucellosis interface appears to be expanding. Managers are faced with decreasing budgets with which to combat brucellosis, so a better understanding of which management strategies are most cost-effective, and where to implement them, is necessary (Schumaker *et al.* 2012). The costs of many available management strategies have already been evaluated (Roberts *et al.* 2012; Kauffman *et al.* 2012), but their potential net benefits have not been evaluated.

The United States Department of Agriculture – Animal Plant Health Inspection Service (USDA-APHIS, from here forward, "APHIS") requested a cost-benefit analysis of management strategies aimed at reducing brucellosis seroprevalence in elk. To objectively evaluate the net benefit of management strategies, we must first understand the relationship between elk brucellosis seroprevalence and risk to cattle. Although multiple risk assessments of *B. abortus* transmission from wildlife to livestock have been performed (Kilpatrick *et al.* 2009; Schumaker *et al.* 2010; Proffitt *et al.* 2011), these risk assessments have all focused on the northern GYA, where bison are present and there are no elk feedgrounds. Meanwhile, recent cases of brucellosis in cattle and domestic bison have been attributed to elk (Beja-Pereira 2009).

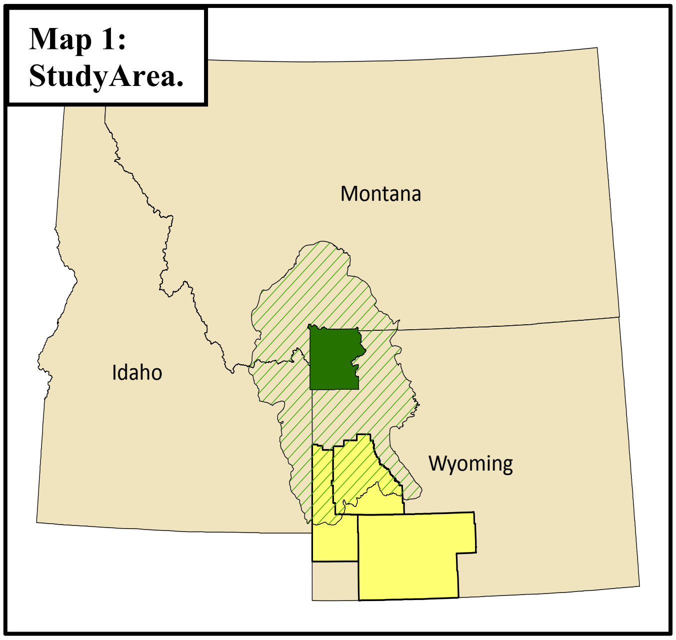
An assessment of the risk of brucellosis transmission from free-ranging elk to cattle in the southern GYA feedground region is needed. A better understanding of the spatial distribution of transmission risk will allow for more targeted applications of available management strategies. The objectives of this study are: 1) model the relationship between elk seroprevalence and resulting transmission risk to cattle, 2) determine the extent to which reduced seroprevalence in elk would reduce the risk of cattle contracting brucellosis (i.e., determine the effectiveness of reducing elk seroprevalence); and 3) estimate the benefits and costs associated with reducing seroprevalence in elk to determine circumstances in which management strategies may be economically justifiable.

This document focuses on the development of a model for elk-cattle overlap during the winter and early spring, which addresses objective 1 above. It is worth noting that this study models risk at a coarse-scale appropriate for evaluating the effects of management at a regional level rather than at an individual or multi-producer level. This model will treat seasons as discrete snapshots in time during which elk and cattle are fixed in space. The results from this model are not intended to be applied to fine-scale questions (e.g. about applying management strategies at the individual ranch or even grazing allotment level); in fact, such outcomes would directly violate confidentiality agreements with participating producers, and would require a much larger budget and longer time-frame than allocated for this analysis. A late spring/summer model is also estimated, but is beyond the scope of this project and will not be discussed. A detailed description of methods used to accomplish objectives 2 and 3 is beyond the scope of this data analysis project, but will be discussed briefly in the discussion section.

METHODS & RISK MODEL RESULTS

Study Area and Data

Animal Locations


Map 1: StudyArea.

While some GPS collar location data has been collected for southern GYA elk, the elk collared for these studies are largely feedground elk and do not represent a random sample of all elk in the area. Additionally, much of this data is proprietary and not available for use in this project. For these reasons, we used a mail survey of cattle producers in Sublette, Lincoln, and Sweetwater counties to gather information for development of a spatial risk model. This method of data collection has been used with success to model bovine tuberculosis transmission risk between elk and cattle in Canada (Brook and McLachlan 2009). Producers were asked to provide information on locations of their cattle herd(s) throughout the year and whether or not elk have been observed overlapping with cattle herds at these locations. Producers were also asked a variety of questions regarding their perceived level of risk and any brucellosis risk mitigation strategies currently implemented, however, the analysis of this information is beyond the scope of this analysis.

In 2007, the tri-county area contained approximately 105,000 cattle under operations by over 500 producers (NASS 2007). This area contains 15 of the state's 23 elk feedgrounds, and several confirmed brucellosis cases in cattle have occurred in this region since standardized record-keeping began in 1987 (USDA-APHIS unpublished data). In February 2012, we hosted public meetings for producers in Pinedale and Big Piney, WY, to disseminate information about the upcoming survey and answer any questions regarding the intended use of the survey data. Surveys were mailed out in late February/early March 2012 via the National Agriculture Statistics Service (NASS). Producers were offered two means of participation: 1) they could complete the enclosed survey, or 2) if they had completed a similar survey (called a "herd plan questionnaire") as part of a herd plan agreement with the Wyoming State Veterinarian, they could allow the State Veterinarian's office to release their survey for use in this study. The survey instrument was designed to be very similar to the herd plan questionnaire for consistency of data, and is available in Appendix 1 (please note that the survey contained a series of maps which producers could use to indicate their herd’s locations; these are not included in this report for the sake of space). Portions of the herd plan questionnaire have changed numerous times throughout the past 10-15 years and the herd plan questionnaire is therefore not shown.

Of the 89 producers who responded in some fashion, 50 supplied sufficiently detailed information for inclusion in this analysis. Twenty-five of the usable responses came from producers in Lincoln County, 16 from Sublette County, and 10 from Sweetwater County (including one overlapping with Sublette County). Information from these 50 producer surveys/herd plan questionnaires was used to digitize cattle herd locations in space (henceforth referred to as “cattle herd polygons”) and to identify these areas as having elk observed (1) or not observed (0) (Map 2), which was used as the dependent variable for a risk model for elk-cattle overlap. Eleven of the fifty producers included in the analysis indicated that elk were seen among cattle during Jan-May, while the remaining 39 producers indicated that no elk were seen (elk presence: yes=1, no=0).

For each cattle herd polygon, zonal statistics (ArcMap 10, ESRI) were used to determine the level of each habitat characteristic of interest occurring within the polygon. The respective level of each habitat characteristic (e.g. mean, majority[1]) for a given producer polygon were used as independent variable inputs into the logistic regression and regression tree models. Definitions and descriptive statistics for all predictor variables considered are provided in Appendix II.

Land Cover

In winter, elk are known to select for navigable terrain. This is often terrain that does not accumulate deep snow while still providing quality forage, such as shrubland areas with little timber (Unsworth *et al.* 1998, Boyce *et al.* 2003, Sawyer *et al.* 2007, Profitt *et al.* 2010). 30-meter National Land Cover Dataset (NLCD; Fry *et al.* 2011) data was used to represent available habitat types. Within the tri-county study area, 16 specific land cover types are represented. To simplify, a new layer, *NLCDmajorREC* is created by reclassifying this layer into 2 categories representing shorter vegetation and taller vegetation types. For each cattle herd polygon, the majority reclassified land cover class is extracted to represent the majority land cover type within that cattle herd polygon.

Predation Pressure

Wolves

Elk are likely to avoid areas with wolves (Brooks and McLachlan 2009; Proffitt *et al.* 2010). A raster surface depicting the probability of wolf presence predicted via a deductive model was provided by Wyoming Natural Diversity Database (Mark Andersen personal communication). This information was used to determine the maximum probability of wolves

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[1] Note: median would have been a particularly useful measure, however, this was not available as a zonal statistics option in ArcMap 10. Mean was therefore used instead.

occurring within a cattle herd polygon. Cattle herd polygons are small enough that if wolves are very likely to be present in any part of the polygon, the effect is likely to be realized polygon-wide.

Additionally, there is evidence that elk alter habitat selection in the presence of wolves, preferring to utilize and remain near areas of wooded cover (Creel *et al.* 2005, Mao *et al.* 2005) or private land refuges (Proffitt *et al.* 2009). A multiplicative interaction term between distance to forest edge and maximum wolf presence, *forestwolf*, was created to represent this relationship.

Humans

Elk respond to the presence of human hunters similarly, but more strongly, than they do to wolf presence (Proffitt *et al.* 2009). Although the majority of hunting occurs during the fall months (WGFD 2013) elk are known to move onto and remain on private land refuges (where landowners may not allow hunting access) in response to hunting pressure (Haggerty and Travis 2006, Proffitt *et al.* 2009), and some areas have late season hunts that could influence elk movements well into the winter/early spring risk period. 2011 WGFD hunter harvest data (WGFD 2012) was used to determine the number of active hunters by elk herd unit in 2011. This number was divided by the square kilometers of the respective elk hunt area to calculate a uniform density of hunters (number of hunters per km^2) within the elk herd unit. The variable *meanhuntersqkm* represents the mean hunter density within a cattle herd polygon.

Roads

Elk generally avoid roads (Witmer and deCalesta 1985; Rost and Bailey 1979; Sawyer *et al.* 2007; Proffitt *et al.* 2010). The Euclidian distance to roads (meters) for each cattle herd polygon was created using Major Roads of Wyoming at 1:100,000 (WYGISC). Additionally, road density ($roads/km^2$) within each cattle herd polygon was calculated using the Bureau of

Land Management roads dataset, excluding those classified as "trails" (BLM 2011). For each cattle herd polygon, *meandisttoroad* and *meanroaddens* were calculated.

Snowpack

In an effort to find forage and remain sufficiently mobile, elk tend to avoid areas of deep snow (Boyce *et al.* 2003; Proffitt *et al.* 2010). 4-km Parameter-elevation Regressions on Independent Slopes Model (PRISM) data for November 2010 through April 2011 was averaged to produce a measure of mean winter precipitation. According to regional Snotel data (NRCS 2013), precipitation occurring in November through April is likely to be accumulating snow. For each cattle herd polygon, *meanwinterprecip* represents the mean amount of winter precipitation occurring within that polygon.

Elk Feedgrounds

One of the main purposes for establishment of the elk feedground system in Wyoming was to maintain separation between elk and cattle (Preble 1911). If a cattle herd polygon is near a feedground, elk in the area are likely to be drawn to the feedground and away from potential commingling with cattle. The mean Euclidean distance to feedground, *meanfeeddist*, is calculated for each cattle herd polygon. Additionally, GPS collar data from elk in the Pinedale elk herd unit suggest that individual elk attending feedgrounds in this herd seldom travel more than 25km from the feedgrounds during the winter months, so an additional variable, *within25kmfeed* is considered.

Finally, Euclidean distance to feedground may not be a good measure of elk proximity to feedgrounds; if elk have to cross steep, snow-covered areas to reach the feedground, they may be unable to access the feedground although their Euclidian distance from the feedground is short. To this end, a cost distance surface (ESRI 2011), *feedcostdist,* is produced in ArcMap10 via interaction between slope and Euclidean distance to feedgrounds. To simplify, the "cost" for an elk to travel a given distance to a feedground is higher if the distance to be traversed has a high slope. This process results in a surface where the value of a given raster cell is calculated as the accumulated cost to traverse itself and all intervening cells between that given cell and the target (in this case, a feedground). The units of this measure are not interpretable, however, the values are meaningful relative to one another. The mean value of *feedcostdist* is calculated for each cattle herd polygon to produce the *meanfeedcostdist.*

Elevation, Slope and Aspect

In winter, elk select for lower elevations (Boyce *et al*. 2003; Sawyer *et al.* 2007; Proffitt *et al.* 2010), steeper slopes that are likely to accumulate less snow (Unsworth *et al.* 1998; Proffitt *et al.* 2010), and southerly or south-westerly aspects (Unworth *et al.* 1998; Sawyer *et al.* 2007; Proffitt *et al.* 2010). 30-m National Elevation Dataset (NED, see ned.usgs.gov) data was used to calculate the mean elevation (meters) within each cattle herd polygon. This 30-m NED dataset was also used to calculate the mean slope (degrees) within each cattle herd polygon. Finally, the 30m NED dataset was used to produce a raster surface depicting aspect. This layer was reclassified into N, E, S, W and flat (see Appendix II for details) to determine the majority aspect, *majoraspect*, for each cattle herd polygon. Because elk are thought to prefer southerly aspects during the winter months, *Saspect* (1 for southerly aspect, 0 else) was also considered.

Modeling

Logistic Regression Model

Elk presence (for the purpose of this project, equivalent to elk comingling with cattle) is characterized as a binary outcome –elk are either reported as present (1) or not reported as present (0). This type of binary response variable lends itself to logistic regression, which ensures that the model's predictions as an index of how likely elk and cattle are to co-mingle will be constrained between 0 and 1.

Selecting Variables

Through exploration of all categorical predictors via descriptive statistics and box plots, it was determined that none of these predictors could be included due to lack of variability in the response across categorical levels. The proper structural form for all potential continuous variables was assessed using cubic spline functions. Given the small sample size and relatively few "successes" (i.e. reported elk presences, 11 out of 50 producers reported seeing elk) in the dataset, these results should be interpreted with caution. However, findings suggest that linear specifications are appropriate for all continuous variables other than *slope*, which may be best fit by a logarithmic term.

The full model is:

$$ln\frac{\pi}{1-\pi} = \beta_0 + \beta_1 meanroaddens + \beta_2 meandisttoroad + \beta_3 meanfeedcostdist + \beta_4 meanfeeddist + \beta_5 meanwinterprecip + \beta_6 meanelev + \beta_7 \log(meanslope) + \beta_8 meanhuntersqkm + \beta_9 forestwolf.$$

(Equation 1)

Insignificant variables were dropped sequentially, and the model re-estimated at each stage. AIC scores were estimated for each model (Table 1)(Kutner *et al.* 2004). Additionally, a stepwise AIC model selection procedure was used with similar outcomes. Although the intended use of the risk model as an input into the next stage of modeling precludes selection of a cutpoint for classifying areas into strictly elk and cattle present or elk and cattle not present, actual and predicted values for each candidate model were compared to produce plots of sensitivity and specificity. A cutpoint of 0.25 was used as maximum sensitivity and specificity was achieved for most of the models at or near 0.25. This means that if the model predicted value of the index of comingling exceed 0.25, we will classify this polygon as a “comingled” polygon and, otherwise, the polygon will be classified as “non-comingling”. A high level of sensitivity indicates that we are likely to correctly classify "risky" areas as high risk, and a high level of specificity indicates that we are likely to correctly classify "unrisky" areas as low risk (Table 1).

Table 1. AIC scores and sensitivity/specificity for candidate models.

Model	*meanroaddens*	*meandisttoroad*	*meanfeedcostdist*	*meanfeeddist*	*meanwinterprecip*	*meanelev*	*log(meanslope)*	*meanhuntersqkm*	*forestwolf*	p	AIC	Sensitivity$^{a/}$	Specificity$^{a/}$
1	X	X	X	X	X	X	X	X	X	10	41.71	0.82	0.88
2	X	X	X	X		X	X	X	X	9	39.71	0.81	0.87
3	X	X	X	X		X	X		X	8	37.80	0.91	0.89
4	X	X	X	X		X			X	7	37.39	0.80	0.87
5	X	X	X	X		X		X		7	38.30	0.82	0.82
6	X	X	X	X		X				6	38.76	0.81	0.81
7	X		X	X		X				5	40.68	0.82	0.82

$^{a/}$Given a cutpoint of 0.25

All candidate models were within approximately 4.3 AIC units of one another with approximate sensitivity/specificity 0.8-0.91 given a cutpoint of 0.25. In the interest of selecting the most parsimonious model in consideration of the small sample size, while retaining good model performance, model 7 was selected as the final model. The final model is:

$$ln\frac{\pi}{1-\pi} = \beta_0 + \beta_1 meanroaddens + \beta_2 feedcostdist + \beta_3 meanfeeddist + \beta_4 meanelev$$

(2)

Coefficient estimates for the final model are provided in Table 2. Analysis for outliers was conducted via exploration of deviance residuals. One observation with deviance residual greater than 2 was observed. Removal of this observation did not result in a notable change in coefficient magnitudes or standard errors, and therefore this observation was retained in estimating the final model. Results from the logistic regression model indicate that elk-cattle overlap in winter/early spring is more likely in areas with lower road densities, higher cost-distance to feedgrounds, closer to feedgrounds, and at lower elevations.

Table 2. Final model results.

Variable	Estimate	SE
Intercept	23.97**	9.82
meanroaddens	-2.17**	0.93
meanfeedcostdist	1.39e-04**	5.69e-05
meanfeeddist	-1.78e-04**	8.07e-05
meanelev	-1.06e-02**	4.27e-03

** indicates significance at α=0.05

Use of Model to Produce Risk Map

The logistic regression model can be converted into a risk surface for use as input into the next stage of modeling. The logistic regression model can be converted from log odds into an index of probability by:

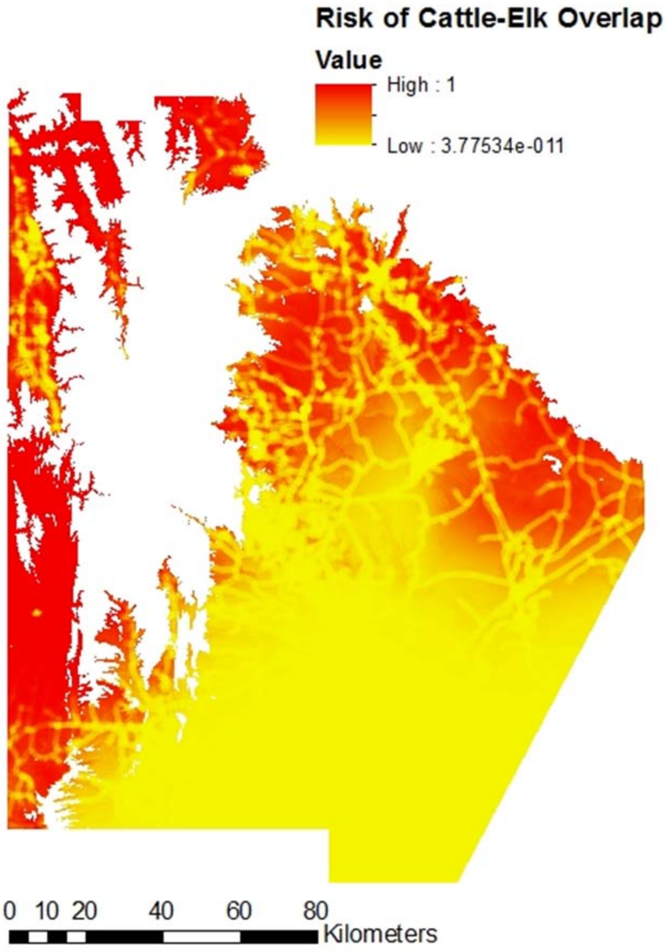
$$\hat{\pi} = \frac{e^{\beta'}}{1+e^{\beta'}},$$

where β'
$=23.97 - 2.17 meanroaddens + \ 0.00014 meanfeedcostdist - 0.00018 meanfeeddist - 0.01 meanelev$. This equation can be directly applied to the relevant raster layers, resulting in a mapped risk surface. Because cattle are kept near producer home places at low elevations during the winter months, our dataset did not contain the full range of each variable that is possible within the study area. This limits our scope of inference to the range of these variables that we did observe. Because many of the variables are associated with elevation, we excluded areas

above 2,500 meters from our output. Areas above 2,500 meters are represented by "No Data" on the output maps. Additionally, we received few samples from Sweetwater County, and we therefore decided to truncate the study area to only the portion of Sweetwater County containing survey respondents.

The risk map output from the logistic regression model (from here forward, "LR risk surface") provides an intuitive, graphical depiction of what the risk model itself describes: during the winter/early spring, the potential for elk-cattle interactions is greater at lower elevations, in areas with lower road densities, further from feedgrounds, and with a high feedground cost-distance. During the winter months, cattle are located at low elevation, on producer home places that are likely to have lower relative road densities and often are positioned adjacent to foothills of major mountain ranges. Elk are known to select for lower elevation areas (Sawyer *et al.* 2007; Boyce *et al*. 2003; Proffitt *et al.* 2010) with relatively steeper slopes that remain windswept with less snow (Proffitt *et al.* 2010; Unsworth *et al.* 1998), and away from roads (Sawyer *et al.* 2007; Proffitt *et al.* 2010; Rost and Bailey 1979; Witmer and deCalesta 1985). The LR risk surface serves to identify areas where elk/cattle interaction may be likely during the winter/early spring risk period. Further steps are necessary to determine the actual risk posed to area cattle from such interactions.

Map 3. Risk of Elk-Cattle Overlap.



An input describing the expected number of elk was created from average herd unit elk populations and WGFD-designated seasonal range. For each herd unit, the average number of elk counted on each feedground (2000-2001 through 2009-2010) was assigned to the polygon designating the boundary of the respective feedground (WGFD personal communication) and subtracted from the 2005-2010 average elk population for the respective herd unit. This resulted in an estimate of the number of elk that do not visit the feedgrounds. These remaining elk were assigned to seasonal range polygons (WGFD personal communication): 1) based on relative importance of the seasonal range type (Table 3), and 2) based on the relative areal proportion of the given seasonal range types within the herd unit.

Table 3. Elk Population Allocation Based on Seasonal Range

Range Classification	Percent of Non-Feedground Elk Population
Crucial winter-yearlong	85%*
Winter year-long	
Year-long	
Winter	
Crucial Winter	
Severe winter	10%*
Crucial severe winter	
Non-designated	5%

* If neither severe winter or crucial severe winter range type exists in the herd unit, 95% of the elk are assigned to the first five range types.

For example, in the Pinedale elk herd unit, the average 2005-2010 elk population is 1,958. An average of 1,726 elk are located on feedgrounds (536 on Fall Creek, 477 on Muddy Creek, and 714 on Scab Creek). Winter seasonal range types designated in the Pinedale elk herd unit include crucial winter, crucial winter yearlong, winter, and winter yearlong. Of the total area designated as any seasonal range type in winter, crucial winter comprises approximately 39%, crucial winter yearlong comprises approximately 45%, winter 1%, and winter yearlong 15%. The remainder of the herd unit is not designated as seasonal range. Of the 232 elk expected to not be using feedgrounds, 95% are assigned to the four seasonal range types (10% would have been assigned to severe winter and crucial severe winter range types if they existed) based on their relative proportion. Approximately 86 elk are assigned to crucial winter, 99 to crucial winter yearlong, 2 to winter, and 33 to winter yearlong. The remaining 12 elk are assigned to non-seasonal range. This process is repeated for each herd unit (Table 4). We assume that elk are uniformly distributed across the landscape within the areas we have assigned them.

Table 4. Expected number of elk on seasonal range types by herd unit.

Herd Unit	2005-2010 average population	feedground average population (2000-2010)	Crucial severe winter	Crucial winter	Crucial winter yearlong	Nonseasonal range	Severe winter	Yearlong	Winter	Winter yearlong
Afton	2313	1558	0	0	278	38	0	0	0	439
Fall Creek	5464	4648	0	16	406	41	0	0	28	325
Hoback	1028	879	0	0	112	7	0	0	0	29
Pinedale	1958	1726	0	86	99	12	0	0	2	33
Piney	3467	2473	0	27	457	50	0	0	259	202
Shamrock	247	0	0	0	0	12	0	234	0	0
South Rock Springs	1481	0	0	0	305	74	0	1093	0	0
South Wind River	4126	0	0	380	512	206	413	696	1148	770

Steamboat	1367	0	0	0	320	68	0	654	0	324
Upper Green River	2567	1840	0	0	120	37	0	0	571	1
West Green River	5300	0	530	1362	681	265	0	0	844	1618

The expected number of elk for each seasonal range type was assigned spatially by linking this information to a shapefile of seasonal range polygons. This shapefile was then converted into a raster layer representing the expected number of elk per grid cell (30x30m = 900m^2). Multiplying the risk surface and expected number of elk layers produces a raster layer representing the number of elk expected to be in contact with cattle. For each herd unit, the sum of all of the raster cells in this resulting layer within that herd unit's boundary represents the total number of elk expected to be in contact with cattle during the winter/early spring risk period. This information can be summarized for the entire herd unit, for the non-feedground areas, and for the individual feedgrounds. The number of years until a cattle case is expected can then be calculated for each herd unit as a function of the number of elk expected to be in contact with cattle, that elk herd unit's female proportion (WGFD JCRs, pregnancy proportion (WGFD personal communication) and seroprevalence (Scurlock and Edwards 2010), and the probability of abortion whether an elk is seropositive or seronegative (WGFD personal communication).

Female proportion

In order to pose a significant brucellosis transmission risk, an elk must be adult, and female. The proportion of each herd unit's elk population that was comprised of adult females was determined from WGFD JCRs for 2007-2011 (WGFD JCRs). @Risk (v. 5.7, Palisade

Corporation, Ithaca, NY) was used to fit triangular distributions for each herd unit. This accounts for variability in the proportion of females in the population from year to year.

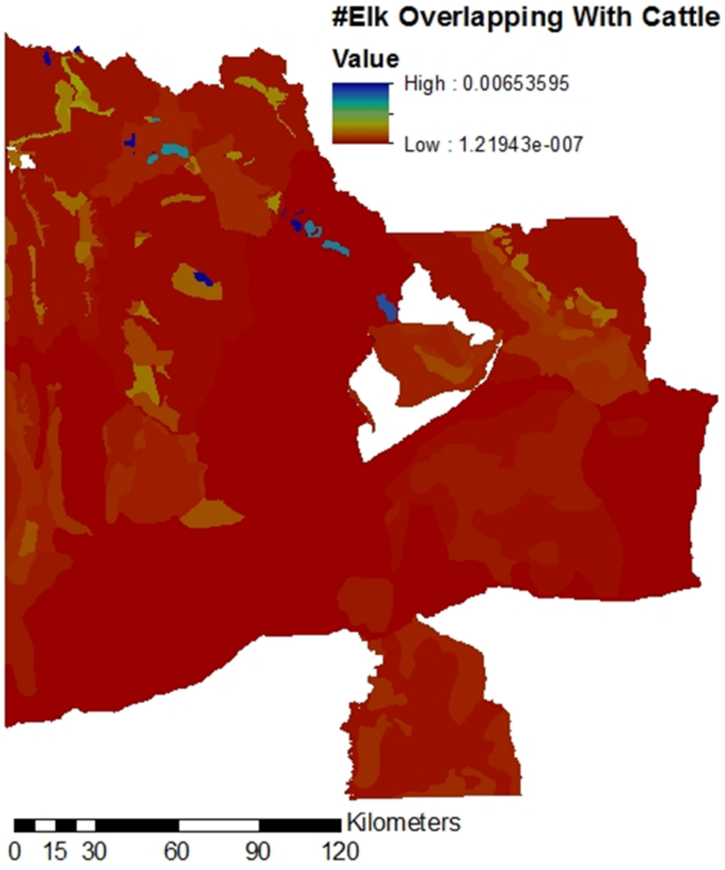
Pregnancy proportion

In addition to being adult and female, an elk must be pregnant in order to transmit brucellosis. According to unpublished WGFD data, approximately 79% of adult female elk tested on feedgrounds are pregnant. To represent this, a beta distribution is fit using BetaBuster software (v1.0, http://www.epi.ucdavis.edu/diagnostictests/betabuster.html). This accounts for the variability in the proportion of females who are pregnant from year to year.

Seroprevalence

Scurlock and Edwards (2010) report seroprevalence as measured from elk within the study area herd units. When information was available from more than one location in a given herd unit (e.g. from two feedgrounds), a triangular distribution was fit to the available data. When only one estimate for seroprevalence was available, this seroprevalence value was used.

Map 4. Number of elk overlapping with cattle.



Likelihood of abortion if seropositive

Given the uncertainty associated with currently available diagnostic tests, an elk that tests positive for antibodies to brucellosis is not necessarily (currently) infected with the bacteria. Unpublished WGFD data suggests that approximately 54% of adult female elk who test positive have culturable bacteria. This is represented by a beta distribution fit using BetaBuster software.

If an elk is seropositive and actually infected, she is not certain to experience an abortive event. Unpublished WGFD data suggests that of those elk that are culture positive, approximately 20.1% will abort. This is also represented with a beta distribution fit using BetaBuster software.

Likelihood of abortion if seronegative

A negative test result does not necessarily mean that an elk is uninfected. Of those elk that test negative, unpublished WGFD data suggests that about 1.7% will abort. This is fit with a normal distribution truncated between 0 and 1.

Table 5. Risk model parameters.

Elk Herd Unit	Expected # Elk Overlapping with Cattle	% Female Triangle(min	% Pregnant	Seroprevalence	P(Abort|Sero+)	P(Abort|Sero-)
			Source			
	Previous modeling step	Fit to data in @Risk	Distribution defined from WGFD unpublished data	Distribution defined from published WGFD data	Distribution defined from unpublished WGFD data	Distribution defined from unpublished WGFD data
			Parameter Specification			
Afton	2.5	Triangular (0.55, 0.68, 0.68)	Beta (40.91, 10.98)	Triangular (0,0.26, 1)	Beta (26.57, 105.23)	Beta (146.75, 126.16)
Fall Creek	.71	Triangular (0.63, 0.63,		Triangular (0.14, 0.33,		

		0.73)	0.33)
Hoback	2.59	Triangular (0.42, 0.68, 0.68)	0.267
Pinedale	2.61	Triangular (0.65, 0.65, 0.70)	Triangular (0.07, 0.22, 0.22)
Piney	3.04	Triangular (0.55, 0.68, 0.68)	Triangular (0.04, 0.37, 0.37)
South Rock Springs	0.0003	Triangular (0.48, 0.48, 0.63)	0
South Wind River	0.82	Triangular (0.6, 0.6, 0.76)	0.015

Steamboat	0.2	Triangular (0.0.35, 0.59, 0.59)	0
Upper Green River	1.07	Triangular (0.0.55, 0.67, 0.67)	Triangular (0.05, 0.257, 0.257)
West Green River	2.8	Triangular (0.59, 0.59, 0.65)	0.01

Because cattle are confined to small areas during the winter/early spring, we assume for purposes of this modeling framework that an elk abortion occurring within a cattle winter feeding area will be contacted by at least one cow. The expected number of cattle cases per year due to winter events can be estimated as:

$$\#\ Cattle\ Cases =$$

$$[(\#\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x\ (Seroprevalence)x\ \big(P(Abort|Sero\ +)\big)]$$

$$+$$

$$[(\#\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x\ (1 - Seroprevalence)x\ x\ \big(P(Abort|Sero\ -)\big)\ ]$$

(Equation 3)

Where parameters are distributions, a monte carlo simulator was used to sample the distribution and return a value and then plugged into Equation 3. The model was then iterated to create probability intervals.

The inverse of equation 3 gives the number of years until a cattle case is expected. All variables are modeled probabilistically and therefore the output (years until cattle case expected) is a distribution. Because management implications are the same whether one or more cattle test positive, we are not concerned with modeling the potential for multiple cattle testing positive. The predicted median number of years until a cattle brucellosis case is expected for each herd unit can be compared to historical data on cattle cases in the region (USDA-APHIS, personal communication) to evaluate the model for accuracy (Table 6).

Table 6. Years until expected cattle case.

Elk Herd Unit	True Cases	Minimum #	Modeled Median

	Since 1989[1]	Years to True Case[1]	(Min, Max) # Years to Expected Case
Afton	0	0	9.0 (3.21, 90.93)
Fall Creek	0	0	17.14 (11.78, 32.56)
Hoback	0	0	4.70 (3.56, 7.02)
Pinedale	1	23	6.96 (4.18, 14.91)
Piney	1	23	4.09 (2.52, 18.96)
South Rock Springs	0	0	554,011 (194,346.16, 687,490.89)
South Wind River	0	0	95.0 (43.04, 318.00)
Steamboat	0	0	719 (277.54, 1,110,392.96)
Upper Green River	0	0	16.09 (9.61, 47.28)
West Green River	0	0	32.5 (14.53, 137.97)

This modeling framework can then be used to model the effect of reducing elk seroprevalence on the risk of cattle contracting brucellosis within the Pinedale elk herd unit. Three high-interest strategies have been identified and will be modeled: 1) test-and-slaughter, 2) low-density feeding, and 3) elk vaccination with strain 19. Because all three of these strategies are implemented at the feedground level, risk to cattle is redefined as:

$$
\begin{aligned}
&\#\,Cattle\ Cases \\
&= [(\#Nonfeedground\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x \\
&(Seroprevalence)x\ \big(P(Culture+|Sero+)\big)x\big(P(Abort|Culture+)\big)] \\
&+ \\
&[(\#Nonfeedground\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x \\
&(1-Seroprevalence)x\ \big(P(Abort|Sero-)\big) \\
&+ \\
&(\#Feedground\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x\ (Seroprevalence)x \\
&\big(P(Culture+|Sero+)\big)x\big(P(Abort|Culture+)\big)] \\
&+ \\
&[(\#Feedground\ Elk\ Overlapping\ with\ Cattle)x\ (\%\ Female)x\ (\%\ Pregnant)x\ (1 \\
&-Seroprevalence)x\ \big(P(Abort|Sero-)\big)\ ]
\end{aligned}
$$

(Equation 4)

This is identical to the risk equation described in Equation 3, but it is separated into feedground and nonfeedground elk components. For the Pinedale elk herd unit, of the 2.614 elk expected to be in contact with cattle (Table 5), 0.007 are associated with feedgrounds, while the remaining 2.607 are not. This information is used as a starting point for modeling reductions in elk seroprevalence via the three following strategies:

Test-and-Slaughter

Test-and-slaughter is modeled by removing sufficient females from the feedground population to effect a desired percentage change in seroprevalence, resulting in reduced seroprevalence, female proportion, and number of elk expected overlapping with cattle. This strategy is implemented on all three Pinedale elk herd unit feedgrounds.

Strain 19 Vaccination

Strain 19 vaccination is modeled on all three Pinedale elk herd unit feedgrounds by lowering seroprevalence without removing any animals.

Low-Density Feeding

Finally, low-density feeding is modeled by lowering seroprevalence on the two Pinedale elk herd unit feedgrounds where low-density feeding is logistically feasible (Fall Creek and Muddy Creek).

Because the effectiveness of these management strategies is largely unknown, 1%, 5%, and 10% reductions in seroprevalence (from a starting value of 18%), and a reduction of seroprevalence to 5% (the lowest level achieved via Test-and-slaughter (Scurlock *et al.* 2010)), are modeled. We then recalculate risk to determine by how many years each management strategy may delay the next expected cattle case (Table 7). This provides a measure of the expected benefit of implementing a management strategy given the current level of seroprevalence.

Figure 1. Simulation results from test and slaughter simulation.

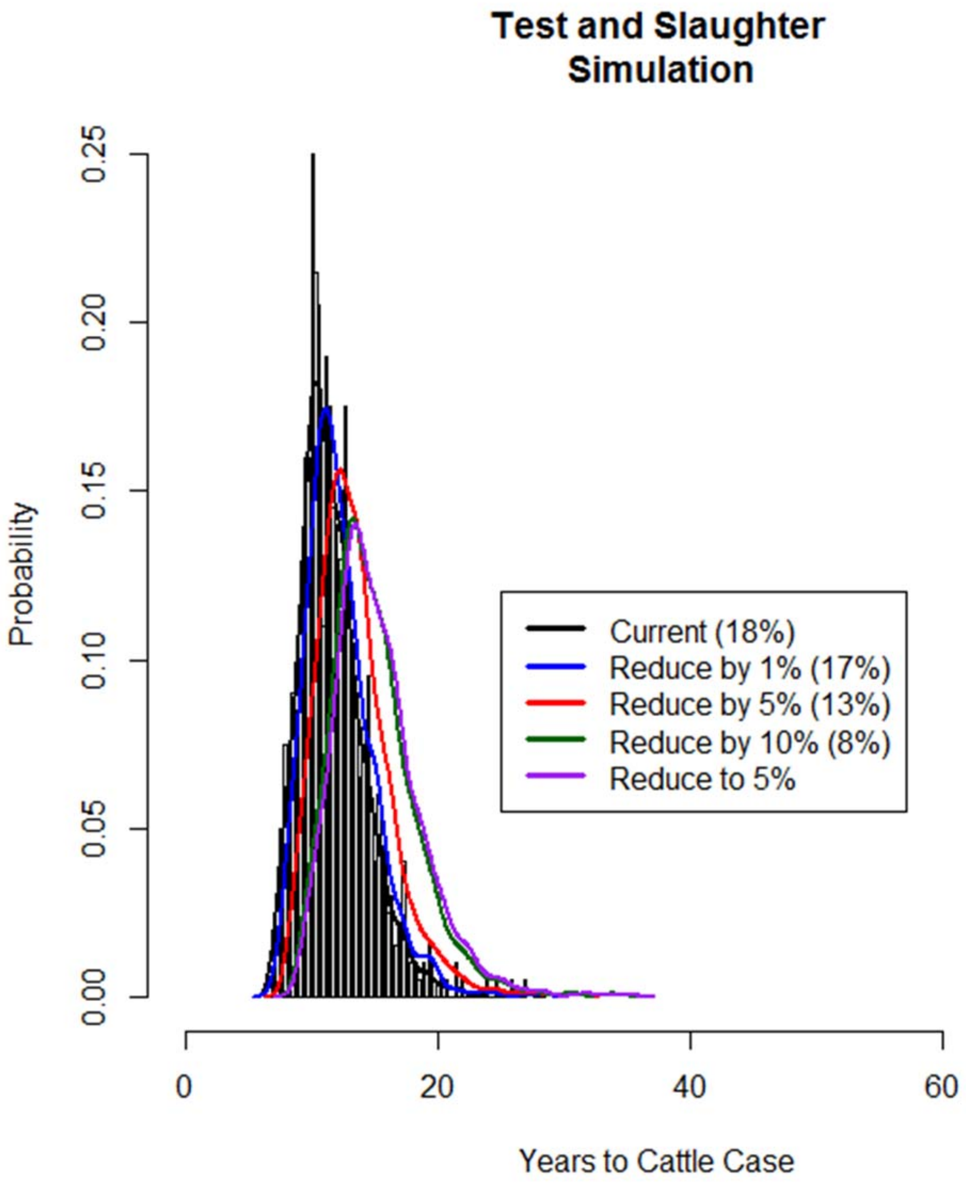


Figure 2. Simulation results from S19 elk vaccination simulation.

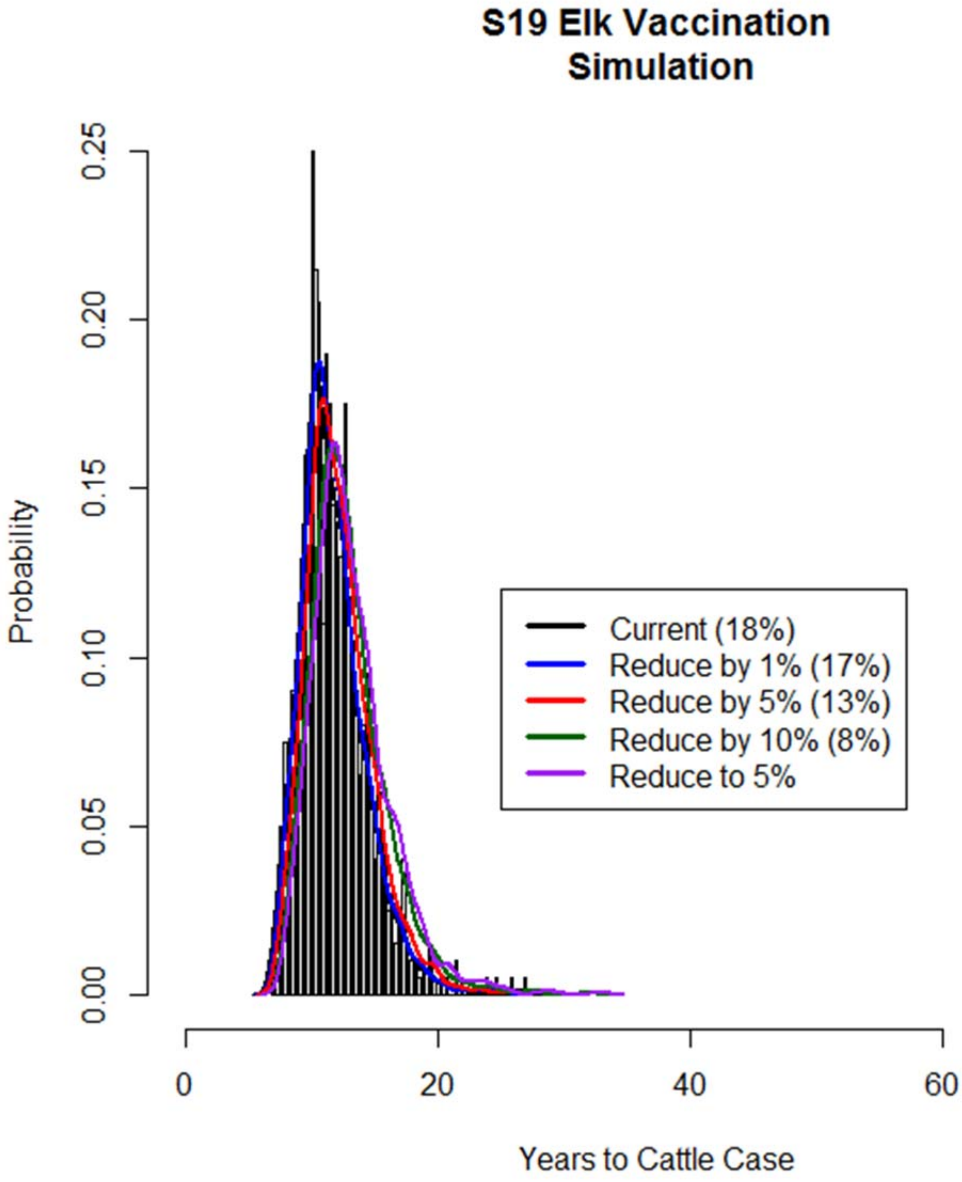


Figure 3. Simulation results from low-density feeding simulation.

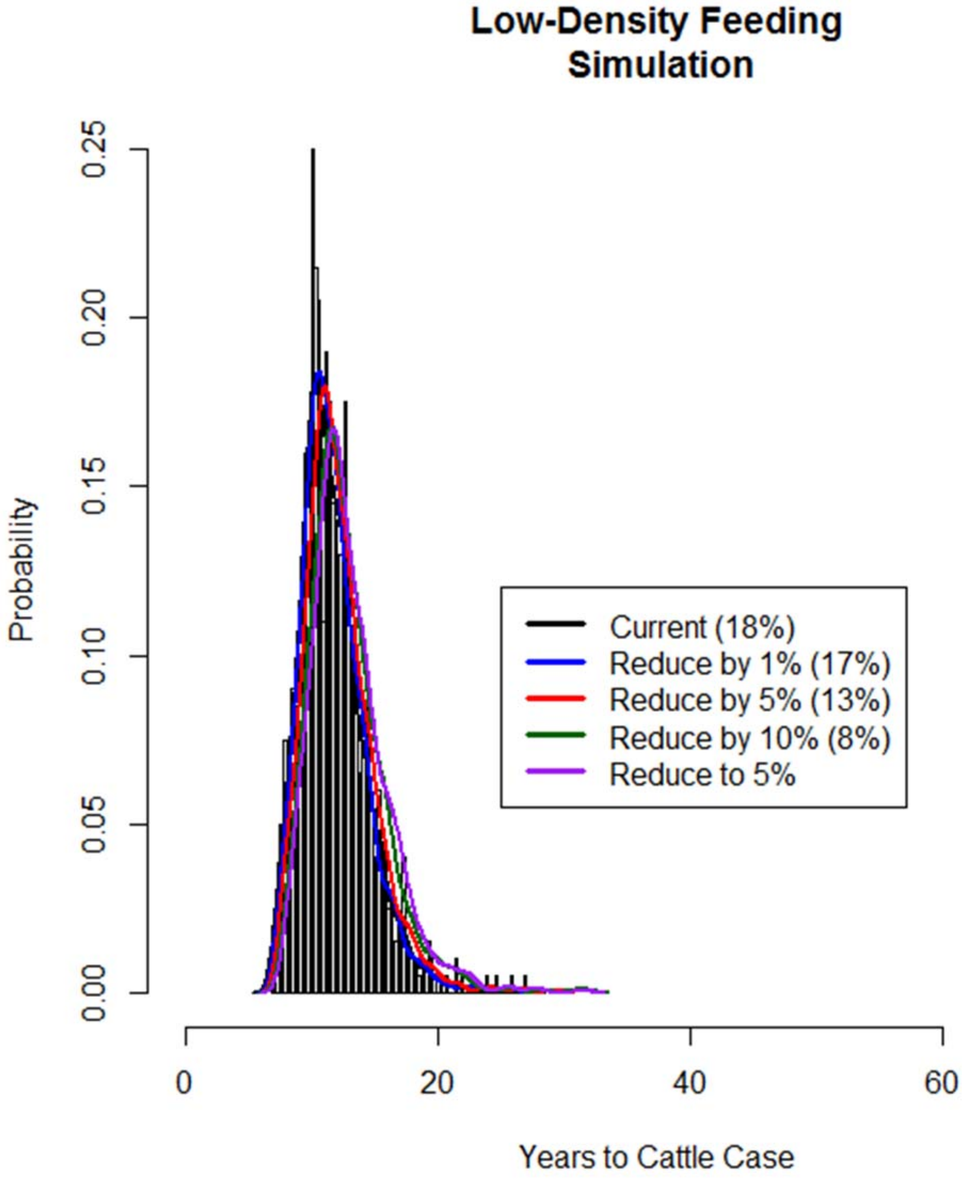


Table 7. Median (5%, 95%) years to expected cattle case under modeled management strategies and seroprevalence reduction scenarios.

	Seroprevalence Reduction Scenario				
Strategy	Current (18%)	-1% (17%)	-5% (13%)	-10% (8%)	to 5%
Test-and-slaughter					
Median		11.81	12.91	14.44	14.71
5%		8.14	8.91	9.88	10.09
95%		18.97	20.57	22.89	23.07
S19 Vaccination					
Median	**11.30**	11.41	11.81	12.43	12.61
5%	**7.75**	7.62	8.15	8.57	8.64
95%	**17.72**	17.84	18.36	19.74	20.82
Low-density Feeding					
Median		11.41	11.73	12.33	12.50
5%		7.88	8.10	8.37	8.63
95%		17.90	18.38	19.94	20.30

Economic Benefit of Reduced Seroprevalence

The primary purpose of reducing seroprevalence in elk is to reduce the frequency of cattle outbreaks and associated losses. Therefore, the economic benefit of reducing seroprevalence in elk depends, in part, on the magnitude of losses experienced during a cattle outbreak. Magnitude of losses depend on the number of herds involved in the outbreak, the number of cattle in each affected herd, duration of the outbreak, response policies in place, cattle prices during the outbreak, and forage availability and price during quarantine. A wide variety of outbreak scenarios could be imagined, each with their own economic cost.

For the purpose of this study, we construct a hypothetical outbreak that affects a single cattle herd containing 400 bred cattle (368 of which will calve successfully in the spring), 80 replacement yearling heifers, 280 yearlings (i.e., calves from the previous year, which will be marketed at approximately 18 months old), and 23 bulls (Wilson 2011, pp. 66-76 and 177-197). The infection is detected on January 1st, at which time the herd is quarantined until it passes three consecutive whole-herd tests. Test-eligible animals include all reproductively-intact animals older than six months of age, of which there are 503, plus an additional 180 female calves that will be born and reach test-eligible-age during the quarantine. We assume all 280 non-replacement yearlings are castrated or spayed (the former is a typical practice, but the latter involves costs not typically incurred), so they do not need to be tested or quarantined, and can be marketed as usual. We assume it takes twelve months for the remaining portion of the herd to test-out of quarantine.

During the quarantine, all test-eligible animals are confined to an interior pasture that shares no fenceline with adjacent herds. Forage within the pasture is insufficient to support the quarantined herd, so supplemental hay is provided for 365 days of the year, instead of the typical 150 days. Female cattle receive 30 lbs/head/day; bulls receive 36 lbs/head/day. Hay is assumed to cost $89/ton (all prices are adjusted to the year 2010), and is by far the largest expense incurred during the outbreak. The total cost of a year-long quarantine, from the perspective of our hypothetical cattle producer, is estimated to be $146,299, including testing and spaying costs among all other expenses (Wilson 2011, pp. 76; adjusted to include the cost of testing 180 female calves, in response to a recent change in the test-eligible-age from 12 months to 6 months). Although we use this cost estimate throughout the rest of our analysis, readers should keep in mind that a change in hay price could dramatically increase or decrease the cost of a year-long quarantine. Also note that our cost estimate does not account for the quarantine and testing of contact herds. The number of contact herds has varied widely across past outbreaks, from zero to well over a dozen; the size of contact herds and length of quarantine has also varied dramatically. No ‘typical’ scenario could be identified for contact herds, so their costs were not included in this analysis. As a point of reference, however, the cost of testing and quarantining a 400-head contact herd is estimated to vary from $2,235 (for a 1-month quarantine in January) to $49,054 (for a 6-month quarantine from January through June, assuming no private pasture is available, such that the herd must be fed 75 days longer than usual) (Wilson, 2011).

The estimated cost of a brucellosis outbreak, $146,299, must now be translated into the benefit of reducing elk seroprevalence. First, the cost of an outbreak must be expressed in an annual timeframe, so it can later be compared with the annual cost of reducing elk seroprevalence. Brucellosis outbreaks in cattle do not typically occur every year in the GYA. We must therefore weight the cost of a brucellosis outbreak by the probability of an outbreak occurring in a given year.

Table 7 reports the predicted frequency of an outbreak in cattle under various elk seroprevalence levels. Under current seroprevalence levels (18%), a cattle outbreak is expected once every 11.30 years (median). Assuming the outbreak has an equal probability of occurring in any one of the 11.30 years, this implies a 1 / 11.30 (or 0.0885) chance. The expected annual cost of a cattle outbreak is therefore $146,299 * 0.0885, or $12,947 under current seroprevalence levels. That is, if a producer set aside $12,947 each year for 11.30 years (without earning interest on it), they would accumulate just enough money ($146,299) to cover the cost of one outbreak. As elk management practices reduce seroprevalence, and cattle outbreaks become less frequent, the expected annual cost of an outbreak also declines (Table 8a). The difference in expected annual cost between the current situation and various management strategies gives us an estimate of a management strategy's expected benefit (i.e., the prevention of expected outbreak-related losses) (Table 8b). The final steps in our economic analysis are to calculate each management strategy's annual cost and subtract it from its expected annual benefit, which results in an estimate of the strategy's expected annual net benefit. The next section describes annual cost estimates for the three elk management strategies of interest.

Table 8a. Expected annual cost of an outbreak under various seroprevalence scenarios. Derived by dividing the cost of an outbreak in cattle ($146,299) by the years to expected cattle case (Table 7). Values below are derived using Median (5%, 95%) values presented in Table 7.

	Seroprevalence Reduction Scenario				
Strategy	Current (18%)	-1% (17%)	-5% (13%)	-10% (8%)	to 5%
T&S					
Median		$12,388	$11,332	$10,132	$9,946
5%		$17,973	$16,420	$14,808	$14,499
95%		$7,712	$7,112	$6,391	$6,342
S19					
Median	$12,947	$12,822	$12,388	$11,770	$11,602
5%	$18,877	$19,199	$17,951	$17,071	$16,933
95%	$8,256	$8,201	$7,968	$7,411	$7,027

LDF				
Median	$12,822	$12,472	$11,865	$11,704
5%	$18,566	$18,062	$17,479	$16,952
95%	$8,173	$7,960	$7,337	$7,207

Table 8b. Expected annual benefit of reducing elk seroprevalence by various amounts. Derived from Table 8a by subtracting ‘expected annual cost under reduced seroprevalence’ from ‘expected annual cost under current seroprevalence’). Positive values indicate a reduction in the expected annual cost of a brucellosis outbreak in cattle (i.e., a positive benefit of reducing elk seroprevalence). Values below correspond to Median (5%, 95%) values presented in Table 7.

	Seroprevalence Reduction Scenario				
Strategy	Current (18%)	-1% (17%)	-5% (13%)	-10% (8%)	to 5%
T&S					
Median	n/a	$559	$1,615	$2,815	$3,001
5%	n/a	$904	$2,458	$4,070	$4,378
95%	n/a	$554	$1,144	$1,865	$1,915
S19					
Median	n/a	$125	$559	$1,177	$1,345
5%	n/a	-$322	$926	$1,806	$1,945
95%	n/a	$56	$288	$845	$1,229
LDF					
Median	n/a	$125	$475	$1,082	$1,243

5%	n/a	$311	$816	$1,398	$1,925
95%	n/a	$83	$296	$919	$1,049

Economic Cost of Elk Management Strategies

Detailed budgets were developed to determine the cost of various management strategies. Multiple cost estimates exist for each strategy because the strategy can be implemented in several different ways. Price information for inputs required to implement strategies were obtained from online and local retailers. Management strategy descriptions and technical specifications were primarily given by WGFD personnel and feedground managers, although other sources also provided critical information, and are described under each management strategy.

Low-Density Feeding

In traditional feeding, hay is spread in a continuous line across the feedground. Low-density feeding, in contrast, uses multiple feedlines adjacent to each other, which has been shown to reduce the number of contacts an elk herd has with a fetus on the feedground (Maichak et. al., 2009). Low-density feeding requires more space than traditional feeding, which is readily available on some feedgrounds, but not on others. Each feedground's physical space and topography are unique; therefore, the ability to support low-density feeding varies across feedgrounds.

Feeding has traditionally been done using a team of horses and a sleigh. One person (elk 'feeder' contracted by the WGFD) usually feeds by themselves, and it can be difficult to simultaneously control the horses and hay dispersal, especially without a calm and experienced horse team. Sometimes the feeder is assisted by a family member, but this second person is not paid. Hiring another person can enable low-density feeding in this situation (Maichak personal communication 2012).

Some elk feeders have accomplished low density feeding by switching to a tractor and feeding implement to better control hay dispersal. Alternatively, other feeders have switched from a tractor to horses in order to access rougher terrain. One has added an extra horse to feed on steeper hills than the two horse team would allow (Maichak personal communication 2012). In the best circumstances, when there is ample space to feed, and when horses are performing well with little direction from the manager, low-density feeding may only require extra time. Under any feeding system, it takes an additional hour to feed using the low density pattern compared to the traditional pattern for herd of 500 elk (Maichak personal communication 2012).

Low-density feeding costs depend on methods of implementation. Prices of tractors, feeding implements, horses, harnesses and sleighs were collected from internet and local dealers. In addition, maintenance costs for equipment were estimated using an extension bulletin "Estimating Farm Machinery Costs" by William Edwards at Iowa State University and Cross and Perry's (1995) depreciation formulas. Draft horse costs were estimated from online draft team sales, while horse maintenance costs were estimated using the Draft Horse Handbook by Washington State University extension. For this cost analysis, we assume feeding occurs with a team and sleigh, and that only extra time is required to accomplish low-density feeding.

Strain 19 Vaccination

Strain 19 vaccination is carried out yearly using air-powered rifles to shoot elk with biobullets from feed sleighs on each feedground. Each year all elk calves are targeted for vaccination with a success rate between 80% and 100% (Scurlock personal communication 2012). To determine the cost of Strain 19 vaccination, the number of elk vaccinated each year, the labor cost, equipment cost, and the cost of the vaccine itself were obtained. Elk herd numbers and number of innoculations were extrapolated from existing WGFD documents.

Elk feeders are paid extra to carry out vaccination. WGFD employees spend time organizing for vaccination efforts as well as assisting and training feedground managers. Eric Maichak and Brandon Scurlock of the WGFD provided the wages feedground managers earn for vaccination, as well as the time WGFD employees spend on vaccination efforts. Biologist wages and salaries were provided through the U.S. Bureau of Labor Statistics.

Strain 19 vaccine costs were provided by the National Vet Services Lab (NVSL) in Ames, Iowa (Carter personal communication 2012). As the only producer of this vaccine, they package it into biobullets for WGFD use. The cost of ballistic delivery system was provided by Solidtech company.

Test-and-Slaughter

Test-and-slaughter was a five year pilot program located on the three feedgrounds (Muddy, Scab and Fall Creek) on the Pinedale Herd Unit (PHU). The WGFD purchased a large new elk trap for each feedground to facilitate this project. They lured elk into the trap with feed, and tested the elk for antibodies to brucellosis. The seropositive elk were then sent to slaughter. The WGFD created an account specific to this project and recorded all costs, along with the number of trappings, elk tested, and elk slaughtered. However, there were different numbers of trappings and therefore different expenses for each year. To compare multiple trapping scenarios, cost was broken down by trapping event, elk tested and elk slaughtered. The WGFD did not include plowing costs in their account, as plowing was provided by Sublette County free of charge. Costs borne by the county were estimated. The WGFD was quoted a cost of $30,000 for plowing services by a private company. For this benefit/cost analysis, we assume there are two trappings per year, and we assume that the county plows the roads to the feedgrounds.

Depreciation and Inflation Adjustments

All three management strategies considered here require a one-time purchase of items that are used over multiple years. To determine an annual cost, we need to spread purchase costs over the lifespan of the purchased item using the following depreciation formula:

$$R = \frac{V_O * i}{[1-(1+i)^{-n}]}$$

where:

V_o = value of item at purchase

i =discount rate (0.0208)

n = economic life of item.

A discount rate of 2.8 % was chosen because it was the listed 5 year CD rate at Bankrate.com in 2010 (Roberts 2012).

To compare all costs, no matter when they occurred temporally, it was necessary to account for the general price inflation over time. All prices have been adjusted to 2010 levels using producer price indices provided by the 2010 and 2011 Wyoming Agricultural Statistics yearbook. Certain types of costs fluctuate widely over time, such as fuel. If these budgets are used for future projections, the potential changes in prices from 2010 onwards should be considered, particularly for large expenses such as labor and fuel. Table 9 summarizes cost estimates for the three elk management strategies. For detailed budgets from which cost estimates are derived, see Appendix III for low-density feeding, IV for strain 19 vaccination, and V for test-and-slaughter.

Next, we examine the potential net benefit of the elk management strategies. As explained earlier, the benefit of elk seroprevalence management is estimated by comparing the expected annual cost of a cattle outbreak without management (current) to the expected annual cost of a cattle outbreak with a management strategy in place. Expected benefit (EB) of a strategy is calculated as follows:

$$\text{EB} = \frac{\$146{,}299}{\begin{matrix} median\ years \\ to\ cattle\ case \\ (current) \end{matrix}} - \frac{\$146{,}299}{\begin{matrix} median\ years \\ to\ cattle\ case \\ (strategy) \end{matrix}}$$

The expected *net* benefit of a management strategy is then equal to expected benefit minus the annual cost of that strategy (Table 10).

Table 9. Cost estimates for three elk management strategies.

Strategy	Minimum Cost	Maximum Cost	Unit	# Units Used per Year	Annual Total Cost Assumed
T&S[a]	**$409,111**[b]	$447,196	2 trappings at each of 3 feedgrounds per year	1	$409,111
S19[c]	$2,094	**$2,522**	Per feedground per year	3	$7,565[d]
LDF[e]	**$2,078**	$18,040	Per feedground per year	2	$4,156

[a] See Appendix V for cost-estimate details.

[b] Costs in bold are those assumed to hold in the subsequent net benefit analysis.

[c] See Appendix IV for details.

[d] Assuming vaccination occurs on 3 feedgrounds within the Pinedale Herd Unit, with each feedground incurring the ‘maximum’ cost of $2,522. This cost is used, instead of ‘minimum’ cost, because it better represents costs at feedgrounds in the Pinedale Herd Unit.

[e] See Appendix III for details. These cost estimates account only for *additional* expenses incurred due to low-density feeding, as compared to traditional feeding.

Table 10. Expected net benefit of elk management strategies under various seroprevalence reduction scenarios.

	Seroprevalence Reduction Scenario				
	Current	-1%	-5%	-10%	
Strategy	(18%)	(17%)	(13%)	(8%)	to 5%
T&S					
Median		-$408,553	-$407,497	-$406,297	-$406,111
5%		-$408,208	-$406,654	-$405,042	-$404,734
95%		-$408,568	-$407,968	-$407,247	-$407,197
S19					
Median		-$7,440	-$7,006	-$6,388	-$6,220
5%		-$7,887	-$6,639	-$5,759	-$5,620
95%		-$7,509	-$7,277	-$6,720	-$6,336
LDF					
Median		-$4,031[a/]	-$3,681	-$3,074	-$2,913
5%		-$3,845	-$3,340	-$2,758	-$2,231
95%		-$4,073	-$3,860	-$3,237	-$3,107

[a/] Assuming the lowest cost of LDF ($2078)

CONCLUSIONS

Economic Analysis

Costs exceed estimated benefits for all three elk management strategies. If society is risk-neutral (i.e., only willing to pay as much for a management strategy as its expected benefit), it should not invest in any of these management strategies. Only if society is risk-averse (i.e., willing to pay more for a management strategy than its expected benefit to gain greater certainty), should it consider investing in any of the management strategies. Low-density feeding has the least-negative net benefit, and should therefore be at the top of a risk-averse society's list of potential management strategies in which to invest. Additional work is needed, but investment in relatively inexpensive cattle management strategies might generate higher net benefits. Research by Roberts *et al.* (2012) suggests that hazing elk from private cattle feedlines, fencing haystacks, and perhaps even adult-booster vaccination (if background risk is sufficiently high) would not have to be very effective to be economically justifiable. Although test-and-slaughter generates the largest benefit amongst the three management strategies, its costs are significantly larger than its benefits. Even if society is highly risk averse, it would be difficult to justify investing in this strategy.

Cost estimates are based on a specific set of assumptions about the location at which strategies are implemented, and the way in which they are implemented. Costs are likely to change with location and approach. We modeled several different approaches for each strategy. Maximum cost was roughly 10, 20, and 868 percent of the minimum cost for test-and-slaughter, S19 vaccination, and low-density feeding, respectively. Net benefit estimates for test-and-slaughter and low-density feeding were based on minimum cost, so they represent the most optimistic outcome (yet, they are still negative). The net benefit estimate for S19 vaccination was based on the maximum cost, but even if minimum cost were used instead, net benefit would still be negative by five to six-thousand dollars.

Cost estimates are based on US$2010 prices. If real prices (i.e., nominal prices with inflation removed) change, due to shifts in market demand or supply, costs will need to be re-estimated. Some prices fluctuate more dramatically than others, such as fuel prices, and some management strategies are more fuel-dependent than others. An increase in the real fuel price, holding all other costs constant, could therefore cause one management strategy to suddenly become more or less attractive than another strategy (i.e., the ranking of strategies could change).

The benefit of elk management strategies depends, in part, on the cost of an outbreak in cattle. Our analysis assumes a hypothetical outbreak that affects a single herd of 400 bred cows, and no contact herds (Wilson, 2011). The index herd is assumed to have no additional reactors and is therefore released from quarantine after 12 months. We assume the hay price is $89 per ton, the average price in 2010. This is significantly lower than current prices, but we are currently feeling the market effects of multiple years of severe drought, which we hope will not become the new normal. Lastly, the outbreak has no impact on cattle prices for cattle, in general, that originate from the GYA. If the expected size of an outbreak is larger, or a herd is culled instead of quarantined, or hay prices are higher, or APHIS imposes statewide testing in response to a particular outbreak, or any other assumptions do not reflect reality, then the cost of a cattle outbreak might be larger, and consequently the expected benefit of elk management strategies might also be larger.

Although our analysis suggests the three management strategies generate negative net benefits, they might generate additional benefits that we have not quantified in this analysis. For example, efforts by WGFD to manage brucellosis in elk might engender good-will with cattle producers, whose private property often provides important habitat for numerous wildlife species. This good-will might encourage producers to continue providing such valuable public goods, or to match the WGFD's brucellosis management efforts with their own. Traditional economic theory would suggest, however, that any reduction in brucellosis risk accomplished by WGFD could potentially reduce cattle producers' incentives to invest their own resources in brucellosis prevention strategies. This ignores recent advances in behavioral economics, however, which suggest people are motivated not only by profit, but also fairness/equity.

Assuming our epidemiological risk model and management strategy costs are accurate, we can back-out how costly a cattle outbreak would have to be to justify strategy investment by a risk-neutral society. Under the seropositive reduction scenario that has the highest benefit (Table 8b, rows ‘5%’, column ‘to 5%’), which is the most optimistic scenario we have analyzed, a cattle outbreak would need to cost the following amount for the strategy to be economically justifiable: $316,000 for low-density feeding; $569,000 for S19 vaccination, and $19.9 million for test-and-slaughter. These numbers are quite large, relative to the assumed cost of $146,299 for a cattle outbreak. Their large magnitude is attributable either to the relatively high cost of a management strategy (Table 9) or its relative ineffectiveness at delaying the occurrence of the next cattle outbreak (Table 7).

Epidemiological Risk Model

Risk estimates from the epidemiology model are consistent with the frequency of outbreaks seen in the GYA over the last few decades. Nonetheless, there have been few outbreaks with which to ground-truth predicted versus actual transmission events. Our model results suggest that the risk arising from feedground elk does not contribute significantly to our overall risk estimates. Keep in mind, however, that our analysis is conducted on a relatively course spatial scale. It also focuses on specific subsets of the risk period, winter through early-spring, and late-spring through summer. The shoulder season, early spring to late spring, is a separate source of risk arising from migrating elk that we did not analyze. Other research groups are currently looking at this source.

Wildlife management agencies should consider focusing their brucellosis efforts on cost-effective strategies for reducing elk populations, group sizes, and densities. They must keep in mind, of course, that such reductions will generate costs because of reduced hunter satisfaction and demand. Risk of a brucellosis outbreak in cattle can be reduced, of course, by preventing contact with infected elk. It is difficult, however, to move elk to areas away from cattle. Conversely, it is expensive to delay cattle grazing in high-risk areas that overlap strongly with elk winter habitat (Roberts *et al.* 2012).

Although our analysis focuses on three elk management strategies, it provides insights that can be applied to other management strategies. Test-and-slaughter reduces risk by reducing elk numbers and seroprevalence. These effects are similar to those expected of immunocontraception. Low-density feeding reduces the number of contacts adequate for disease transmission and thereby reduces seroprevalence. Winter habitat improvement would have similar effects on disease dynamics. Somewhat similarly, S19 vaccination reduces adequate contacts by reducing the number of transmission events and hence eventually reducing seroprevalence. No other management strategy comes to mind that has similar effects, although new strategies are always in development.

Limitations and Future Research Needs

As mentioned above, our modeling framework treats winter/early spring and late spring/summer as discrete seasons. In reality, elk move between their winter and summer ranges during what is known as the "shoulder season". This may be a high-risk period for cattle, particularly those whose shoulder season location is within the elk migratory path from feedground to summer range. Elk moving through the area during this time may still be reasonably likely to abort and cattle could be exposed.

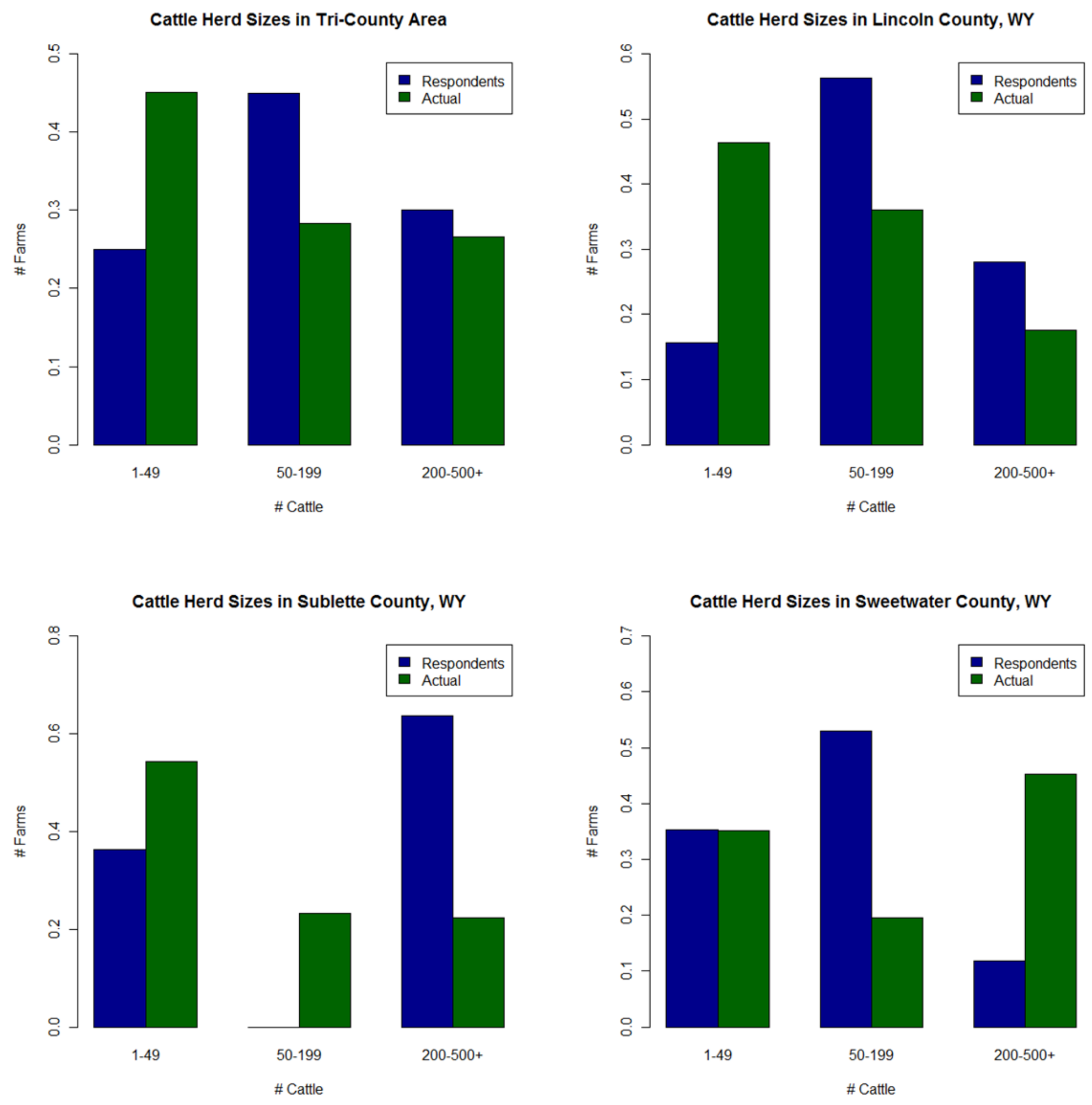
Additionally, risk is not likely to be static throughout entire seasons as elk may move around throughout the area despite remaining at lower elevations. Levels and types of risk may differ throughout the risk periods, and different suites of management strategies may be appropriate as risk changes. More detailed information from producers could allow for modeling month-by-month or on some time-scale other than seasons; however, extracting such information from producers has proven difficult. This level of detail would likely require in-person interviews with producers rather than a mail survey, which would certainly increase both time and monetary costs.

Another limitation of this analysis is that it is constrained by producer participation. Although the survey was sent to 483 producers in 3 counties, 89 producers responded (18% response rate, 10% usable response rate). Our original intent was for only those producers from the tri-county area whose cattle spend at least some portion of the year within the Pinedale elk herd unit to respond. We received few responses specific to the Pinedale elk herd unit, and many responses from producers who operate outside of this area. Because of the small sample size, we opted to include all responses from within the entire tri-county survey area. Of the producers who did respond, not all provided sufficient detail to allow mapping of their cattle herds, and therefore not all respondents could be included in the analysis. Because follow-up contact with respondents was limited to those who provided permission, additional information often could not be gathered to fill in missing pieces in unusable data. Small producers were under-represented in our sample (Figure 4), and as a result our analysis may not accurately reflect the situations faced by these producers.

Because NASS was used to distribute the survey, identification of and follow-up with non-respondents was not possible. It is possible that non-respondents would have responded differently to some of our survey questions, and therefore our results (especially for future analyses involving the more subjective survey questions) may be biased. This bias, if it does exist, may be further compounded by our inability to detect and potentially correct for it.

Additionally, we must rely on producer responses as truth for this analysis. It is possible that producers may under- or over-report seeing elk among their cattle. Producers may not always observe elk if they are present, and may report elk as not being present in their area when in fact they are. If producers perceive that they may be stigmatized as "high risk" if they report seeing elk among their cattle herds, they may be inclined to under-report elk. Conversely, if producers feel they may receive more management assistance if they are perceived as dealing with "problematic elk", they may be inclined to over-report. Following up with a collared elk

Figure 4. Distribution of respondents' herd size.



Cattle Herd Sizes in Tri-County Area

Cattle Herd Sizes in Lincoln County, WY

Cattle Herd Sizes in Sublette County, WY

Cattle Herd Sizes in Sweetwater County, WY

study in this area would be an ideal means of ground-truthing producer responses. However, the added time and monetary expenses are likely beyond the investment that APHIS is willing to make to hone the evaluation of these management strategies.

To address concerns about the relatively low sample size, additional strategies for sampling are recommended. Our usable sample represented approximately 10% of Lincoln County producers (25 responses from 250 producers present in 2007 (NASS 2007), 12.8% of Sublette County producers (16/125), and 6.8% of Sweetwater County producers (10/148). Given the lack of brucellosis in Sweetwater County elk and the county's distance from the feedground region, future sampling efforts could ignore this area. Additional survey sampling should focus on producers in Lincoln and Sublette counties. Because eliciting usable survey responses via the mail survey proved difficult, I recommend in-person surveys. This would allow researchers to more thoroughly explain the goals of the project, which may increase participation.

In-person interviews would also allow for elucidation of more detailed responses from producers and ensure that the data collected can actually be used for the intended analyses. Although identifying a list of producers such as NASS retains may be difficult, contacts with producers in the area or agencies such as University of Wyoming Extension may be useful in generating a list of producers and addresses to visit. If identifying producers to visit proves impossible, another possibility for reaching producers would be to attend events such as county fairs or livestock shows where producers are likely to be present, and attempt to survey them at these locations with an abbreviated version of the survey. If it is deemed necessary, a stratified survey approach can be used to ensure that the sample matches the known population characteristics as far as herd size and/or county. These strategies would have been ideal from the onset of this project, but their implementation is limited by time and financial constraints.

A second possibility is to collaborate with individuals who have collected GPS collar location data on elk in these counties and/or to collect our own collar data, and combine this data with the available survey data (Brook and McLachlan 2009). This approach may work well to increase sample size, but collecting this type of data is prohibitively expensive and time-consuming for the goals of this project. Also, using GPS collar data collected by others may not be fully representative of area elk, as most studies focus on distinct sub-populations of the area elk herds.

A third option for addressing the sampling concerns described above would be to implement a post-stratification weighting of the usable samples to facilitate a better representation of the underyling population. However, common methods use post-stratification weighting as a means of establishing unbiased estimates of means (Holt and Elliot 1991) rather than for input into regression modeling frameworks. Further exploration of possible techniques is warranted, but beyond the scope of this report.

As mentioned previously, the intent of this analysis is to develop a coarse-scale risk model and utilize it as a tool for evaluating the costs and benefits associated with the suite of management strategies available for reducing bovine brucellosis seroprevalence in elk at a regional level. This model is not intended for applications such as determining appropriate management strategies to implement on a specific ranch or within a given drainage, for example. Despite its limitations, however, this model is sufficient for gaining an understanding of regional risk, and for modeling potential changes in risk as a result of elk seroprevalence reduction strategies.

Attempting to analyze or report results at a finer scale would be in direct violation of confidentiality agreements with participating producers, as such information could result in economic and trade consequences for producers identifiable as operating within higher-risk areas. Such questions, however, are a logical next step in evaluating when and where it makes sense to implement these management strategies. Modeling at this finer scale would require more detailed information on elk locations, and an understanding of elk movements and interactions with cattle over much shorter time frames than the seasonal models we have described in this analysis.

The ideal method for ground-truthing this model and generating a finer scale version to answer some of these follow-up questions would be to collar both elk and cattle in the region and collect data throughout the winter, spring, and summer risk periods. Several companies now produce "proximity collars" which can be used to not only monitor animal locations over time, but can also record interactions at a specified distance with other collared individuals over time. This type of information could be very useful in understanding the risk of elk-cattle overlap, particularly when cattle are on summer grazing allotments where direct observation of this overlap by producers is not feasible. Researchers with both the University of Wyoming and United States Geological Survey are in the midst of estimating RSFs for elk using GPS collar data. Although potentially also problematic in not representing all regional elk, these RSFs will likely be useful as a next step in providing greater insight into the areas where elk may come into contact with cattle (and when) at a finer scale than our analysis. In lieu of additional data, these RSFs could potentially be used to ground-truth portions of our risk assessment and provide recommendations for management strategies at a finer location and time scale.

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APPENDIX I: SURVEY-RELATED DOCUMENTS

Wyoming State Veterinary Laboratory
Department of Veterinary Sciences
College of Agriculture and Natural Resources
University of Wyoming
1174 Snowy Range Road
Laramie, WY 82070

Dear Producer:

We are contacting you regarding a cooperative study being undertaken by the University of Wyoming and the Wyoming Livestock Board. We are conducting this analysis within the Pinedale elk herd unit, which encompasses portions of Sublette, Lincoln, and Sweetwater counties. The goals of our research are:

1) to understand the relationship between the level of brucellosis in elk and risk of brucellosis transmission to cattle,
2) to understand how effectively reductions in the level of brucellosis in elk could reduce the risk of transmission from elk to cattle,
and 3) to evaluate the costs and benefits of management strategies aimed at reducing the level of brucellosis in elk.

To do this, **we are asking for your help**. Much of the information we need to conduct this analysis is contained in herd plan questionnaires that you may have already completed. If you have completed a herd plan questionnaire and are willing to allow the Wyoming Livestock Board share your herd plan questionnaire data with us, please sign the enclosed release form. If you have not completed a herd plan questionnaire, but are willing to share your information with us, we ask that you complete the enclosed survey. Although we request information regarding specific locations of cattle and elk, **we will not report any information that identifies you personally.** Results of the study will be reported broadly and will not identify individual producers or detailed segments of the study area.

The findings from this study may provide direct benefits to you as a producer. The results from our elk-cattle risk model may give you a better idea of what your herd's risk of contracting brucellosis is, and will offer some insights into how effective some of our wildlife-based management strategies are at mitigating these risks. **Your participation is critical for the success of our project.** If we are unable to collect accurate data, our model will not be as accurate and our study's benefit to you will be limited. If you are willing to allow your herd plan questionnaire to be released, please sign and return the enclosed yellow release form. If you are willing to complete the enclosed survey, please sign and complete all of the enclosed white documents. Please return appropriate documents in the postage-paid envelope (also enclosed) as soon as possible.

Please call or email us (contact information below) if you have any questions about the study, brucellosis, or if you have concerns about the confidentiality of information you provide.

Thank you in advance for your interest and partipation.

Sincerely,

Mandy Kauffman	Brant A. Schumaker, DVM/PhD	Dr. Jim Logan
Graduate Student	*Epidemiologist and Assistant Professor*	*Wyoming State Veterinarian*
(307)766-9971	*(307)766-9970*	*(307)857-4140*
mkauffma@uwyo.edu	*bschumak@uwyo.edu*	*jim.logan@wyo.gov*

CONSENT FORM FOR RELEASE OF HERD PLAN QUESTIONNAIRE

I. This study aims to understand the relationship between brucellosis seroprevalence in elk and risk of transmission to cattle, and how effectively reductions in elk seroprevalence could reduce the risk of transmission from elk to cattle. We will then evaluate the costs and benefits of using management strategies aimed at reducing seroprevalence in elk. Information from area cattle produers is critical to make the modeling effort as realistic as possible. Results from the analysis will help area cattle producers understand their level of risk and offer them insight in evaluating which management strategies to employ.

II. This study will be conducted within the Pinedale elk herd unit. All cattle producers will receive a mailed letter requesting that they consent to allow Wyoming Livestock Board to share their herd plan information. The producer simply needs to sign the form and return it to the Wyoming State Veterinarian in the provided pre-addressed, postage-paid enveloped. This study is being conducted by University of Wyoming researchers, and signing the consent form should take very little of the subject's time.

III. Minimal risk is associated with this study. Researchers at the University of Wyoming will know who the producers are, but this information will only be used to spatially orient the information received. Producer information will never be shared with researchers outside the study and will not be reported in any way. While information on locations of cattle/elk may be sensitive, results of the analysis will be reported at a regional scale and therefore individual producers/specific areas will not be identified.

IV. The modeling effort will be improved by acquisition of data from area producers. Results of the analysis will help producers better understand their herd's risk of contracting brucellosis from area elk, and will help in evaluation of cost-effective use of management strategies.

V. All information will be kept within a locked filing cabinet and pass-word protected computer in a locked office in a secure area of the Wyoming State Veterinary Laboratory, and only researchers affiliated with the project will have access to it. ***The PI will maintain all records and information collected for this study within a locked filing cabinet in a secure area of the Wyoming State Veterinary Laboratory for three years following completion of the research.***

VI. Freedom of consent:

My participation is voluntary and my refusal to participate will not involve penalty or loss of benefits to which I am otherwise entitled, and I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled."

If at any time I wish to disallow my information to be used in the study, I can indicate my desire to do so to either University of Wyoming researcher listed below, or to the Wyoming State Veterinarian.

VII. Questions about the research:

If you have questions about the project, please contact:

Mandy Kauffman, Graduate Student, Department of Veterinary Sciences, University of Wyoming, Wyoming State Veterinary Laboratory, 1174 Snowy Range Road, Laramie, WY 82070. mkauffma@uwyo.edu or (307)766-9971.

Dr. Brant Schumaker, Assistant Professor and Epidemologist, Department of Veterinary Sciences, University of Wyoming, Wyoming State Veterinary Laboratory, 1174 Snowy Range Road, Laramie, WY 82070. mkauffma@uwyo.edu or (307)766-9971.

Dr. Jim Logan, Wyoming State Veterinarian, 610 Fairground Road, Riverton, WY 82501. jim.logan@wyo.gov or (307)857-4140

If you have questions about your rights as a research subject, please contact the University of Wyoming IRB Administrator at 307-766-5320.

VIII.

☐ **I consent to allow the Wyoming Livestock Board to share my herd plan questionnaire responses with University of Wyoming Researchers for the above mentioned research.**

____
Printed name of participant

____ ____________________
Participant signature Date

OR

☐ **I consent to allow the Wyoming Livestock Board to share my herd plan questionnaire responses with University of Wyoming Researchers for the above mentioned research. Personally identifying name and location information will be removed prior to sharing of information, but Wyoming Livestock Board staff can discuss general location information with University of Wyoming researchers.**

____
Printed name of participant

____ ____________________
Participant signature Date

☐ **University of Wyoming researchers may contact me for further information:**

Printed name of participant

Participant signature Date

Preferred method of contact (provide phone or email)

Please return this form in the enclosed pre-addressed, postage-paid envelope to:

Dr. Jim Logan, Wyoming State Veterinarian
610 Fairground Road, Riverton, WY 82501

CONSENT FORM FOR SURVEY

I. This study aims to understand the relationship between brucellosis seroprevalence in elk and risk of transmission to cattle, and how effectively reductions in elk seroprevalence could reduce the risk of transmission from elk to cattle. We will then evaluate the costs and benefits of using management strategies aimed at reducing seroprevalence in elk. Information from area cattle produers is critical to make the modeling effort as realistic as possible. Results from the analysis will help area cattle producers understand their level of risk and offer them insight in evaluating which management strategies to employ.

II. This study will be conducted within the Pinedale elk herd unit. All cattle producers will receive a mailed letter requesting that they complete a survey. The producer simply needs to sign the consent form, complete the survey, and return it to the Wyoming State Veterinarian in the provided pre-addressed, postage-paid enveloped. This study is being conducted by University of Wyoming researchers, and signing the consent form should take very little of the subject's time.

III. Minimal risk is associated with this study. Researchers at the University of Wyoming will know who the producers are, but this information will only be used to spatially orient the information received. Producer information will never be shared with researchers outside the study and will not be reported in any way. While information on locations of cattle/elk may be sensitive, results of the analysis will be reported at a regional scale and therefore individual producers/specific areas will not be identified.

IV. The modeling effort will be improved by acquisition of data from area producers. Results of the analysis will help producers better understand their herd's risk of contracting brucellosis from area elk, and will help in evaluation of cost-effective use of management strategies.

V. All information will be kept within a locked filing cabinet in a locked office in a secure area of the Wyoming State Veterinary Laboratory, and only researchers affiliated with the project will have access to it. ***The PI will maintain all records and information collected for this study within a locked filing cabinet in a secure area of the Wyoming State Veterinary Laboratory for three years following completion of the research.***

VI. Freedom of consent:

My participation is voluntary and my refusal to participate will not involve penalty or loss of benefits to which I am otherwise entitled, and I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled."

If at any time I wish to disallow my information to be used in the study, I can indicate my desire to do so to either University of Wyoming researcher listed below, or to the Wyoming State Veterinarian.

VII. Questions about the research:

If you have questions about the project, please contact:

Mandy Kauffman, Graduate Student, Department of Veterinary Sciences, University of Wyoming, Wyoming State Veterinary Laboratory, 1174 Snowy Range Road, Laramie, WY 82070. mkauffma@uwyo.edu or (307)766-9971.

Dr. Brant Schumaker, Assistant Professor and Epidemologist, Department of Veterinary Sciences, University of Wyoming, Wyoming State Veterinary Laboratory, 1174 Snowy Range Road, Laramie, WY 82070. mkauffma@uwyo.edu or (307)766-9971.

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□ I consent to allow the Wyoming Livestock Board to share my herd plan questionnaire responses with University of Wyoming Researchers for the above mentioned research.

____
Printed name of participant

____ ____________________
Participant signature Date

OR

□ I consent to allow the Wyoming Livestock Board to share my herd plan questionnaire responses with University of Wyoming Researchers for the above mentioned research. Personally identifying name and location information will be removed prior to sharing of information, but Wyoming Livestock Board staff can discuss general location information with University of Wyoming researchers.

____
Printed name of participant

____ ____________________
Participant signature Date

□ University of Wyoming researchers may contact me for further information:

____
Printed name of participant

_______________________________________ ____________________
Participant signature Date

____
Preferred method of contact (provide phone or email)

Please return this form in the enclosed pre-addressed, postage-paid envelope to:

Dr. Jim Logan, Wyoming State Veterinarian
610 Fairground Road, Riverton, WY 82501

Producer Information:

Name of Ranch: ____

Owner: ____

Physical Address of Ranch: ____

City, State, Zip: ____

Mailing Address: ____

City, State, Zip: ____

E-mail Address: ____

Phone Numbers: ____

Contact Person or Manager (if not owner): ________________________________

Phone Numbers: ________________________Cell Phone:__________________

Date operation started: ________________________________

Cattle and Elk Information:

1. Operation type (circle all that apply):
   - Beef: commercial
   - Beef: purebred
   - Beef: cow-calf
   - Beef: yearling
   - Dairy

2. Estimated number of sexually intact female cattle in my herd, on average: _______

3. Estimated total number of cattle (all ages, male and female) in my herd, on average: ______

4. Please state where the following events occur and their usual dates of occurrence. Please be as specific as possible.

Location (include County) Dates

Summer Grazing: ____

Fall Grazing: ____

Winter Feeding/Grazing: ____

Spring Feeding/Grazing: ____

5. Do your cattle run in common with other cattle? Yes ___ No ___
   If so, whose: ____
   Where? ____

   Is this land: Private land or Public land (please circle)

6. How would you rate the risk of your herd contracting brucellosis in the next 5 years?
(e.g., at 50%, you could expect to see your herd contract brucellosis 1 out of every 2 years. At 25%, you could expect to see your herd contract brucellosis 1 out of every 4 years.):
☐ No Risk ☐ Very Low (1-15%) ☐ Low (16-35%)
☐ Moderate (36-65%) ☐ High (66-85%) ☐ Very High (86-100%)

7. Do you see elk on your private or leased property? Yes ___ No ___

   If so, please circle all applicable approximate dates:
   Jan- Mar Apr-Jun Jul-Sep Oct-Dec

8. Is this a normal yearly occurrence? Yes ___ No ___

9. Do elk run in common/intermingle with your cattle? Yes ___ No ___

   If so, please circle all applicable approximate dates:
   Jan- Mar Apr-Jun Jul-Sep Oct-Dec

   If so, how often?

	Rarely (Once per season)	Occasionally (Once per month)	Often (Once per week)	Frequently (Daily)	Not Applicable
Jan-Mar					
Apr-Jun					
Jul-Sep					
Oct-Dec					

   What is the typical elk group size you observe? _____________

10. Elk are close to your cattle because: (mark all that apply)

____________ Feedline
____________ Stored feed
____________ Traditional elk habitat
____________ Migratory route
____________ Other: (please describe) ____

11. Do elk have access to areas where your cattle are fed or grazed from January 1 through June 15? Yes ___ No ___

12. How often do you see elk eating hay with or after your cattle?
Never _____ Rarely _____ Occasionally _____ Frequently _____ Does Not Apply _____
What time of year? ____

13. What percentage of your haystacks/stored feed fenced or otherwise made inaccessible to elk? ___

14. Do elk access your stored feed/haystacks? Yes ___ No ___

15. Do your cattle have access to an elk feedground? Yes ___ No ___
What time of year? ____

16. Do your cattle have access to an elk calving ground? Yes ___ No ___
What time of year? ____

17. Do you or others take measures to keep elk out of your feed sources and away from your cattle during the critical exposure risk period between January 1 and June 15?
Yes _____ No _____
What measures are taken? ____
____
____
____

18. On your property or leased land have you ever seen:
1) Elk calving – Yes _____ No _____
2) Evidence of an elk abortion – Yes _____ No _____
How close to your cattle? ____

19. What ideas specific to your operation would serve to resolve the problem of commingling? _
____
____
____
____

20. I allow elk hunting on my private land: ☐ Yes ☐ No

Please continue to the maps on the following pages.

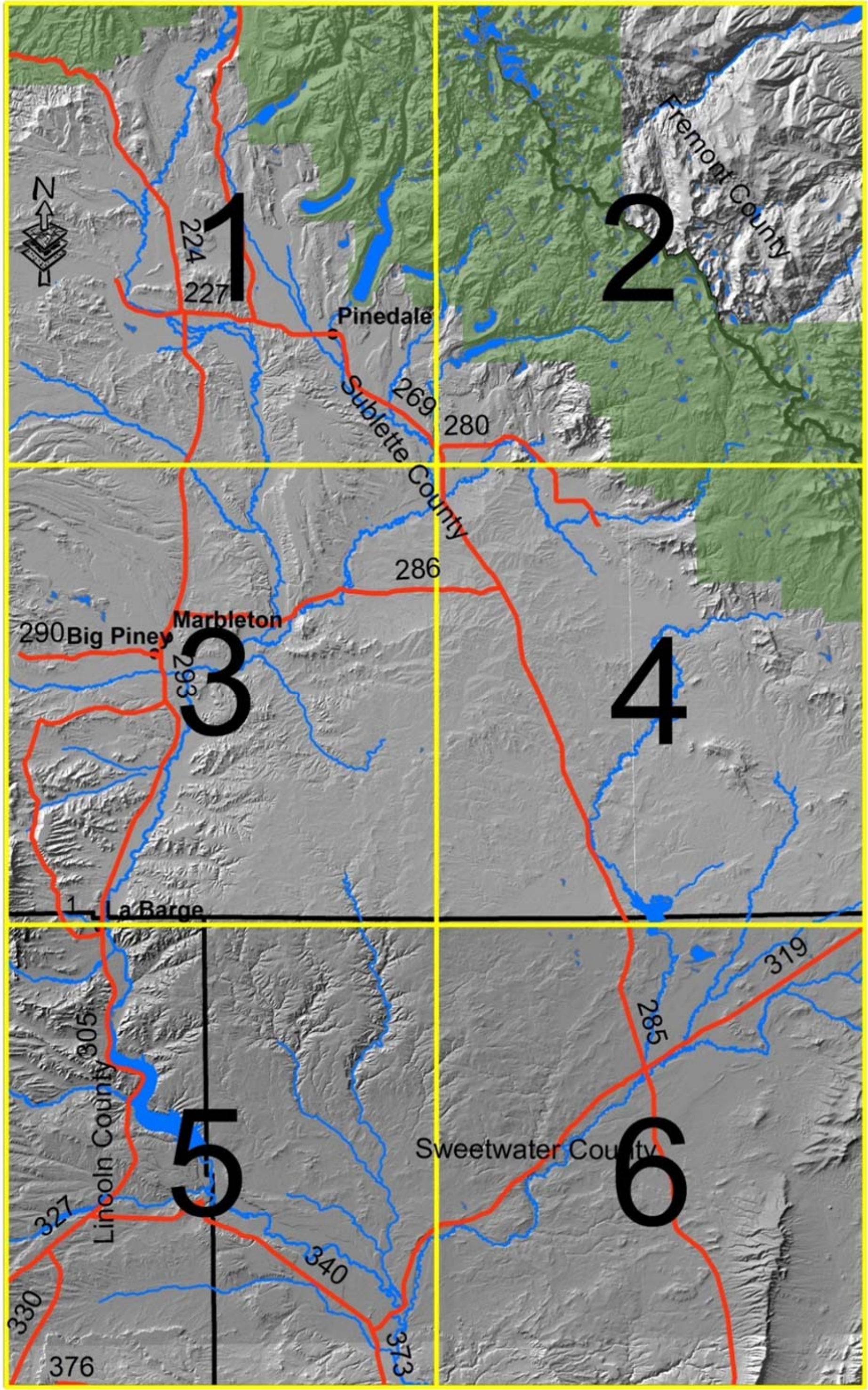
THANK YOU FOR YOUR PARTICIPATION!!!

A. Use the main study area map (below) to identify the segment map(s) you should use to represent your cattle locations.

B. Use the appropriate segment map(s) and tables of grazing allotment names to <u>indicate and identify</u> the areas your cattle use during the following seasons:

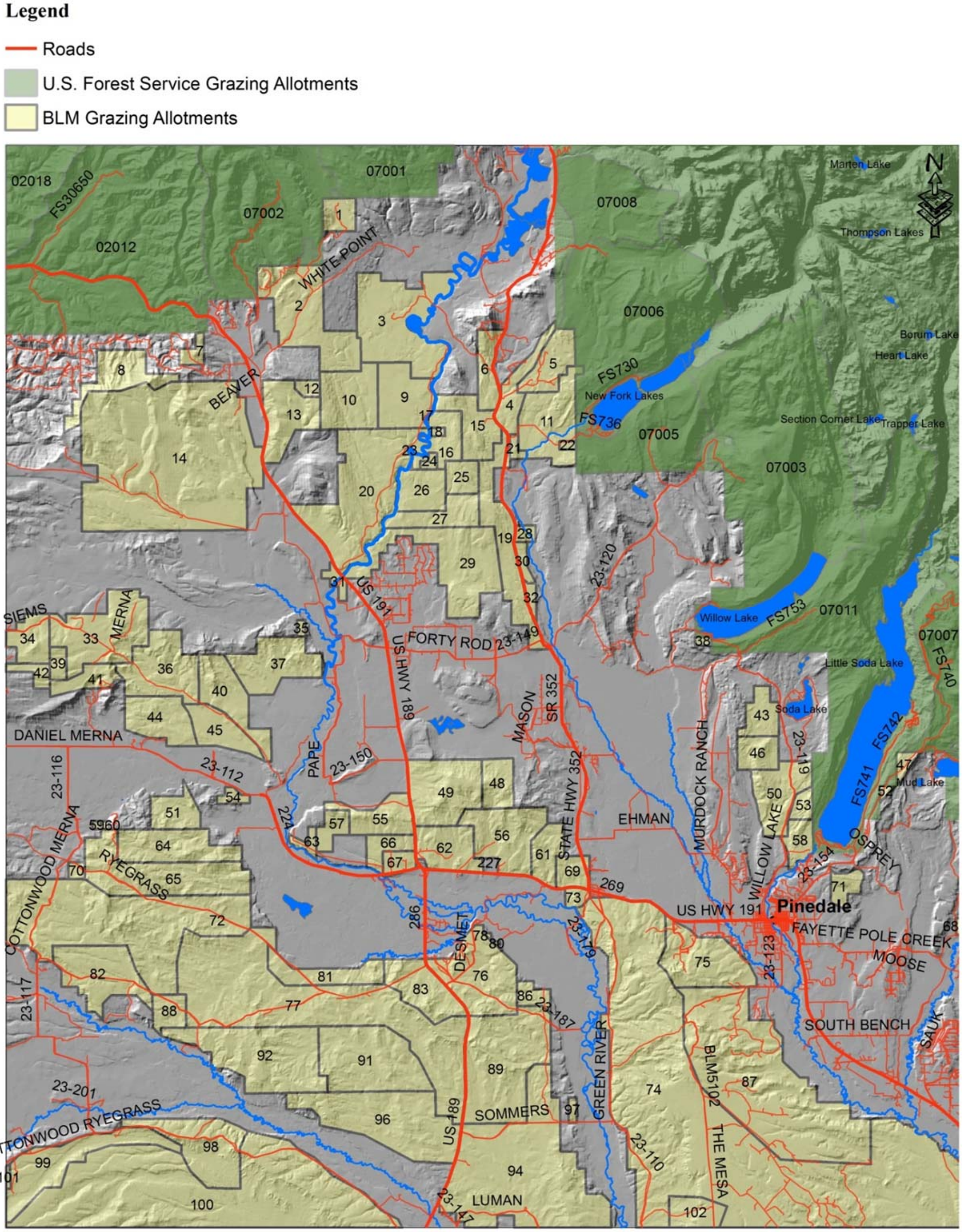
Winter (Nov16-Mar15)*	**Spring (Mar15-May15)***
Early summer (May16-July15)*	**Late summer (July16-Sep15)***
Fall (Sep15-Nov15)*	

***If your seasonal use differs substantially from the season dates listed above, please indicate YOUR season dates.**



N
1
224
227
Pinedale
2
Fremont County
269
Sublette County
280
286
290
Big Piney
Marbleton
3
293
4
1
La Barge
319
305
285
Lincoln County
5
Sweetwater County
6
327
340
330
373
376

SEGMENT 1



Legend
Roads
U.S. Forest Service Grazing Allotments
BLM Grazing Allotments
N
02018
FS30650
07001
07002
02012
07008
07006
07005
07003
07011
07007
Marten Lake
Thompson Lakes
Borum Lake
Heart Lake
New Fork Lakes
FS730
FS736
Section Corner Lake
Trapper Lake
Willow Lake
FS753
Little Soda Lake
Soda Lake
FS740
FS742
FS741
Mud Lake
WHITE POINT
BEAVER
US 191
US HWY 189
FORTY ROD
23-149
23-120
SR 352
MASON
STATE HWY 352
SIEMS
MERNA
DANIEL MERNA
23-112
23-116
PAPE
23-150
224
COTTONWOOD MERNA
RYEGRASS
227
269
US HWY 191
Pinedale
EHMAN
MURDOCK RANCH
WILLOW LAKE
23-119
23-154
OSPREY
FAYETTE POLE CREEK
MOOSE
23-123
SOUTH BENCH
SAUK
286
DESMET
23-176
23-187
GREEN RIVER
BLM5102
THE MESA
23-110
23-117
23-201
COTTONWOOD RYEGRASS
US 189
SOMMERS
23-147
LUMAN
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102

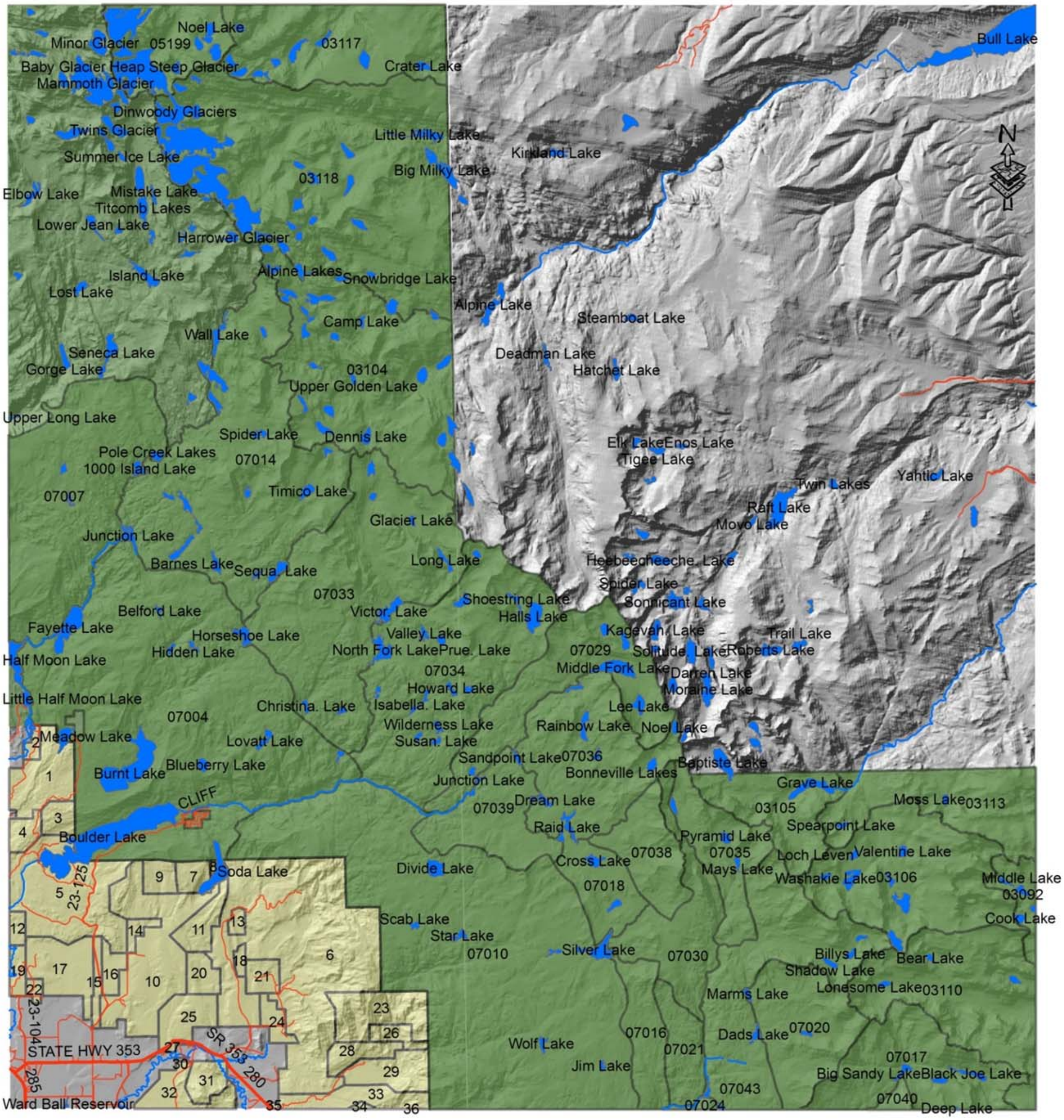
SEGMENT 2

Legend

— Roads

🟩 U.S. Forest Service Grazing Allotments

🟨 BLM Grazing Allotments

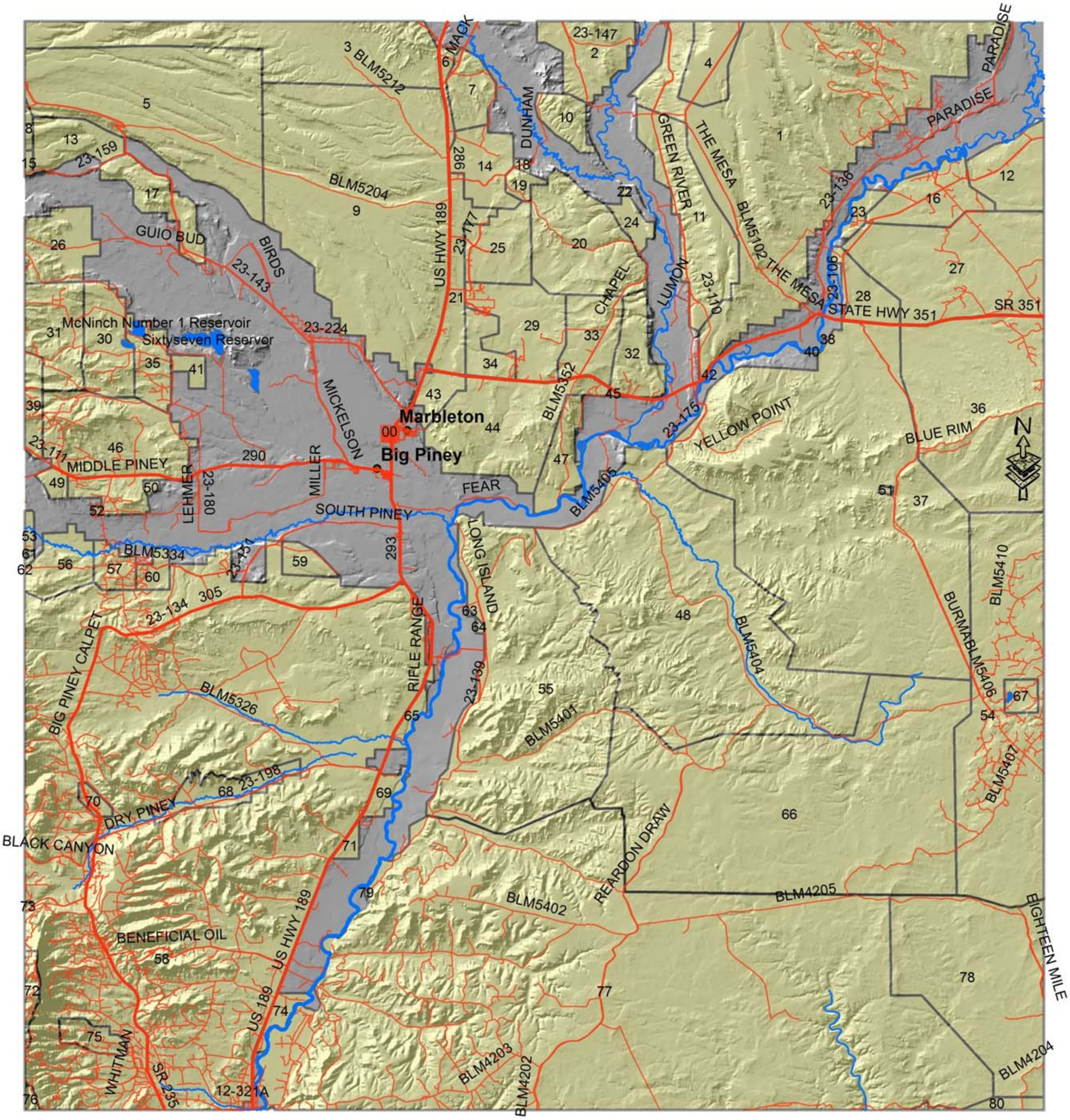


SEGMENT 3

Legend

— Roads

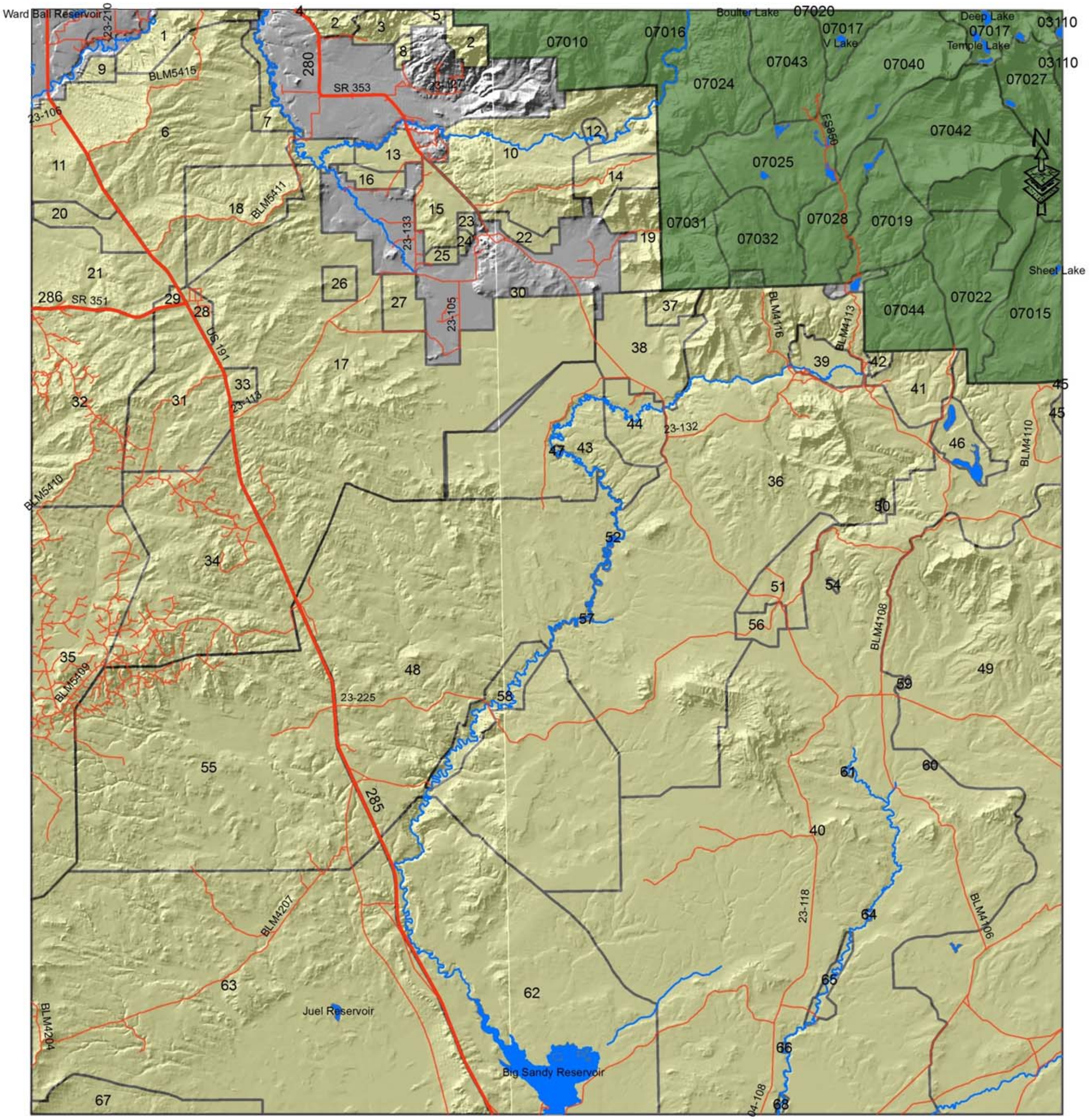
🟨 BLM Grazing Allotments



SEGMENT 4

Legend

- ━ Roads
- ▢ BLM Grazing Allotments
- 🟩 U.S. Forest Service Grazing Allotments

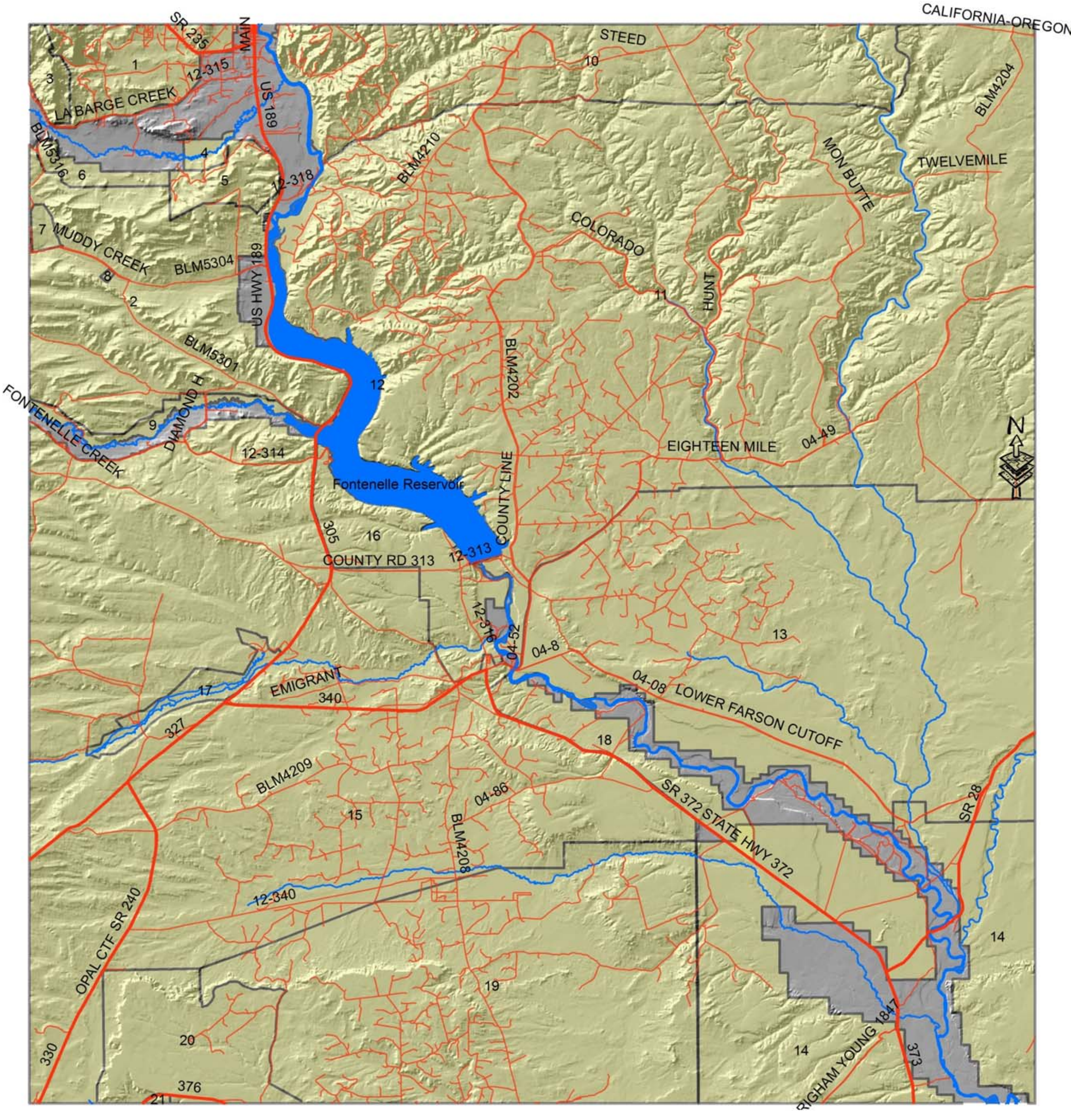


SEGMENT 5

Legend

— Roads

▨ BLM Grazing Allotments

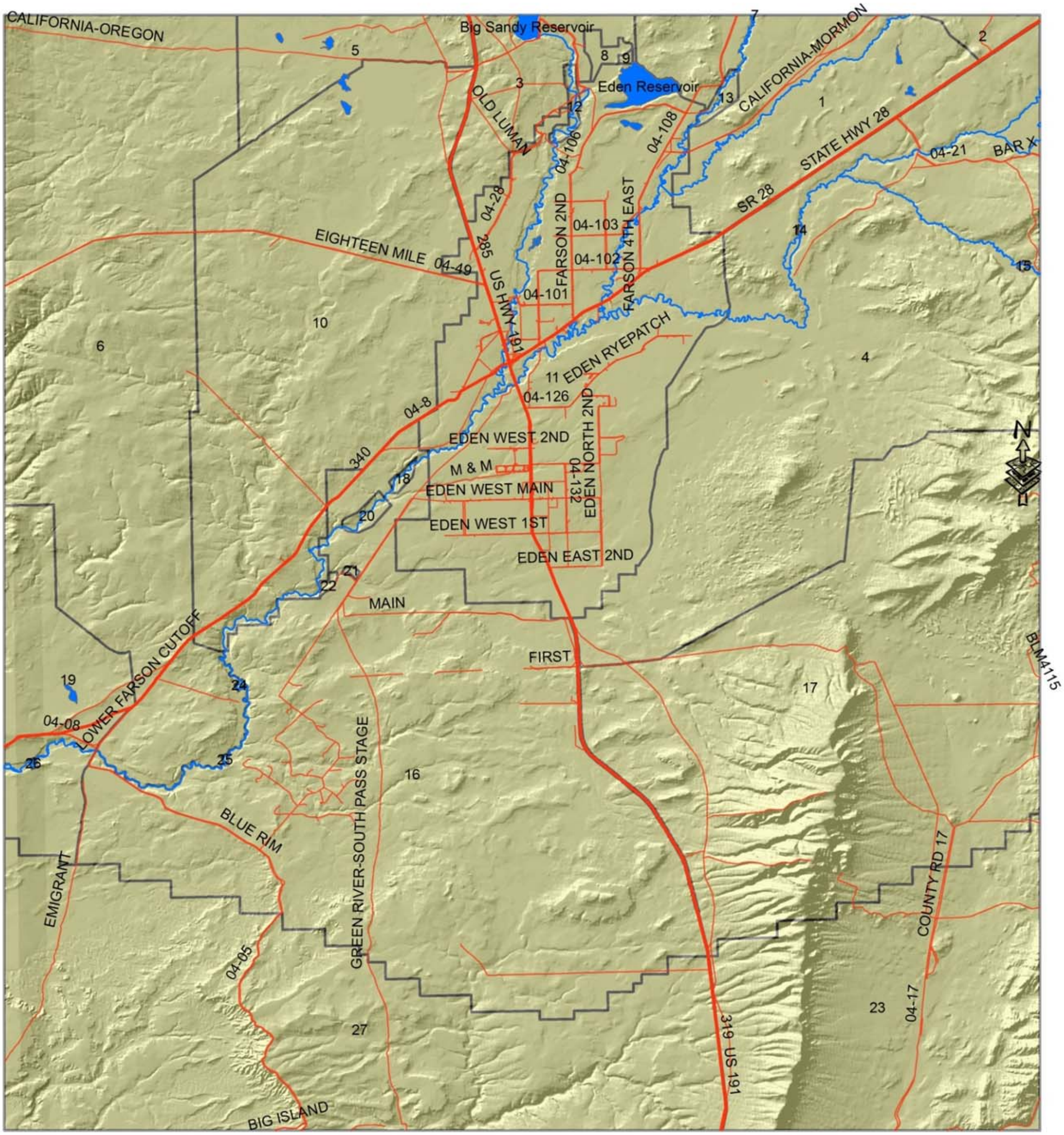


SEGMENT 6

Legend

— Roads

▨ BLM Grazing Allotments



SEGMENT 1

BLM ALLOTMENTS

NUMBER	ALLOTMENT NAME
1	HANSEN TRACT
2	N BEAVER TRACTS I
3	ROSENE IND
4	CORA STOCK DRIVEW
5	DACK INDIVIDUAL
6	LAUZER MARSH CR I
7	N HOBACK RIM IND
8	N HOBACK RIM IND
9	BUYER HORSE CR IN
10	ANTELOPE FLAT COM
11	NOBLE TRACTS IND.
12	HAY DRAW IND
13	Q5 ANTELOPE FLAT
14	HOBACK RIM
15	GLASCOW IND
16	UNKNOWN
17	UNKNOWN
18	UNKNOWN
19	CORA STOCK DRIVEW
20	SPADE IND
21	EAST CORA ROAD IN
22	NEW FORK TRACT IS
23	UNKNOWN
24	UNKNOWN
25	HOMESTEAD IND
26	THREE ISLAND IND
27	CANYON DITCH IND
28	E CORA ROAD MEADO
29	40 ROD COMMON
30	CORA ROAD IND
31	WARREN BRIDGE IND
32	DITCH IND
33	ISOLATED TRACT I
34	LONG PASTURE
35	HORSE CR PASTURE
36	WEBB DRAW PASTURE
37	BEAVER-HORSE CR.
38	WILLOW LAKE TRACT
39	UNKNOWN
40	LOWER PASTURE IND
41	MERNA HORSE CR I
42	HORSE CR IND
43	CHAIN LAKES IND
44	RESERVOIR PAST
45	WEBB HOME PASTURE
46	HAY GULCH
47	FREMONT LAKE IND
48	CORA PEAK IND
49	WEST CORA PEAK IN
50	W FREMONT RIDGE C
51	RYEGRASS ISOLATED
52	FREMONT LAKE IND
53	UNKNOWN
54	HEIFER PASTURE IN
55	FISH HATCHERY IND
56	NOBLE CORA PEAK C
57	MILLER DANIEL RID
58	PINE CR IND
59	CRANOR BUILDING P
60	TODD PASTURE
61	CORA Y COM
62	DANIEL "Y"
63	GREEN RIVER UNIT
64	RYEGRASS INDIVIDU
65	JAMES RYEGRASS
66	J&K DANIEL RIDGE
67	DANIEL RIDGE IND
68	POLE CR IND
69	CORA STOCK DRIVEW
70	BALL HORSE CR IND
71	RIEF INDIVIDUAL
72	EAST ASPEN RIDGE
73	CORA STOCK DRIVEW
74	MESA COM
75	CLARK-BLOOM COM
76	Q5 SOAPHOLE
77	RND VLY-RYEGRASS
78	MILLER HOME PL IN
79	FALL CREEK
80	MILLER HOME PL IN
81	UPPER HORSE CREEK
82	BRODIE DRAW IND
83	LOWER HORSE CREEK
84	BOULDER LAKE COM
85	FALL CR PASTURE
86	PRICE HORSE CR IN
87	MOUNT AIRY COM

88	UNKNOWN
89	GRINDSTONE SOAPHO
90	UNKNOWN
91	HORSE CREEK-RYEGR
92	JEWETT RYE GRASS
93	FAYETTE IND
94	SOAPHOLE COM
95	BOULDER CREEK TRA
96	HORSE CR PASTURE
97	HORSE CR BLUFF IN
98	SCHOOL SECTION IN
99	JOHNSON HUHTAH IN
100	BENCH CORRAL IND
101	UPPER MUDDY IND
102	LUMAN IND

USFS ALLOTMENTS

NUMBER	ALLOTMENT NAME
07011	SODA LAKE
07003	BIG FLATTOP
07002	BEAVER-TWIN
07005	LITTLE FLATTOP
07007	POLE CREEK
02012	FISHERMAN CREEK
07001	BADGER CREEK
07008	POT CREEK
02018	JACK CREEK C&H
07006	NEW FORK-BOULDER

SEGMENT 2

BLM ALLOTMENTS

NUMBER	ALLOTMENT NAME
1	POLE CREEK IND
2	HICKS PINEDALE IND
3	UNKNOWN
4	FALL CREEK
5	BOULDER LAKE COM
6	SCAB CREEK IND
7	UNKNOWN
8	BOUSMAN COMMON
9	UNKNOWN
10	BOUSMAN COMMON
11	SODA LAKE COM
12	UNKNOWN
13	UNKNOWN
14	UNKNOWN
15	BOULDER S D W
16	UNKNOWN
17	SCATTERED TRACTS
18	UNKNOWN
19	BOULDER CREEK TRA
20	UNKNOWN
21	UNKNOWN
22	MCKINSEY IND
23	SAGEBRUSH BASIN
24	UNKNOWN
25	STEELE IND
26	UNKNOWN
27	HOT SPRING PASTURE
28	UNKNOWN
29	SILVER CREEK IND
30	EAST FORK RIVER IND
31	BUTTE IND
32	CHALK BUTTE COM
33	COTTONWOOD COMM
34	GILLIGAN IND
35	UNKNOWN
36	UNKNOWN

USFS ALLOTMENTS

NUMBER	ALLOTMENT NAME
03092	DICKINSON PARK
03104	GLACIER
03105	GRAVE LAKE
03106	LITTLE WIND
03110	TAYO
03113	SAND CREEK
03117	DRY CREEK
03118	PRISTINE
05199	DINWOODY
07004	BURNT LAKE
07007	POLE CREEK
07010	SILVER CREEK
07014	BALDY LAKE
07016	BOUNDARY CREEK
07017	BUNION CREEK
07018	CROSS LAKE
07020	DADS LAKE
07021	EAST FORK
07024	IRISH CANYON
07029	MIDDLE FORK
07030	MT. GEIKE
07033	NORTH FORK
07034	PIPESTONE
07035	PYRAMID LAKE
07036	RAID RAINBOW
07038	SHEEP CREEK
07039	SOUTH FORK
07040	SOUTH TEMPLE CREEK
07043	WASHAKIE-FRANCIS LAKE

SEGMENT 3

BLM ALLOTMENTS

NUMBER	ALLOTMENT NAME
1	MESA COM
2	SOAPHOLE COM
3	BENCH CORRAL IND
4	LUMAN IND
5	BENCH CORRAL COM
6	BENCH CORRAL COM
7	HOME IND
8	UPPER BILLIES IND
9	BENCH CORRAL COM
10	S RIDGE SOAPHOLE
11	MARINCIC MESA IND
12	FREMONT BUTTE COM
13	MICKELSON BRA CO
14	MUDDY CORRAL IND
15	LOWER RED CANYON
16	NEW FORK IND
17	DEAD INDIAN DOME
18	189 MUDDY MEADOW
19	MILLER PINEY IN
20	CHAPEL IND
21	LANDER CUTOFF
22	COTTONWOOD GAP
23	BURCH INDIVIDUAL
24	COTTONWOOD MEAD
25	UNKNOWN
26	GUIO SECTIONS IND
27	BLUE RIM IND
28	BLUE RIM DESER
29	GILCHRIST D L E I
30	MCNINCH DEER HILL
31	DEER HILLS IND
32	PINEY BRIDGE IN
33	EAST OF D L E IN
34	DESERT LAND ENTRY
35	WEST OF RANCH IND
36	BLUE RIM IND
37	BLUE RIM DESER
38	5 ACRE PASTURE IND
39	D BUDD DEER HILL
40	5 ACRE PASTURE IN
41	SECTION 18 IND
42	MESA COM
43	LANDER CUTOFF
44	MULESHOE
45	PINEY BRIDGE IN
46	DEER HILLS COM
47	MUDDY CREEK IND
48	ALKALI DRAW
49	ADJ TO RANCH IND
50	SPENCE PL IND
51	UNKNOWN
52	ADJ TO RANCH IND
53	SOUTH PINEY IND
54	SAND DRAW ALLOT
55	REARDON CANYON
56	LABARGE UNIT IND
57	S PINEY RANCH IND
58	N LABARGE COM
59	O NEIL IND
60	S PINEY PL MEADOW
61	BEAVER TRACT IND
62	BEAVER CR MEADOW
63	JOHNSON PL MEADOW
64	JOHNSON PL MEADOW
65	N LABARGE COM
66	SOUTH DESERT ALLOT
67	UNKNOWN
68	DRY PINEY IND
69	N LABARGE COM
70	UNKNOWN
71	N LABARGE COM
72	UPPER N LABARGE
73	LABARGE IND
74	BIRD INDIVIDUAL
75	JORY IND
76	YOSE IND
77	FIGURE FOUR
78	SUBLETTE
79	UNKNOWN
80	EIGHTEEN MILE

SEGMENT 4

BLM ALLOTMENTS

NUMBER	**ALLOTMENT NAME**
1	CHALK BUTTE COM
2	COTTONWOOD COM
3	GILLIGAN IND
4	UNKNOWN
5	UNKNOWN
6	FREMONT BUTTE COM
7	SANDY FENCED IND
8	HITTLE IND
9	CIRCLE 9 IND
10	EAST FORK COM
11	FREMONT BUTTE COM
12	UNKNOWN
13	INDIVIDUAL FENCED
14	IRISH CANYON TR
15	SQUARE TOP COM
16	NORTH PASTURE IND
17	SQUARE TOP COM
18	FREMONT BUTTE IND
19	SANDY UPPER MUDDY
20	UNKNOWN
21	BLUE RIM IND
22	BIG SANDY IND
23	MUDDY MEADOWS
24	SANDY IND
25	BOULTER PASTURE
26	UNKNOWN
27	SOUTHWEST PAST IND
28	UNKNOWN
29	NW SQUARE TOP IND
30	COWLEY TRACT
31	NW SQUARE TOP IND
32	BLUE RIM IND
33	UNKNOWN
34	STUD HORSE COM
35	SAND DRAW ALLOTMENT
36	PROSPECT MTN
37	RICHIE PASTURE
38	MACK FLAT
39	BIG SANDY RANCH
40	LITTLE SANDY
41	GRASS CREEK
42	RICHIE PASTURE
43	BUCKSKIN SANDY
44	SANDY PASTURE
45	WHITE ACORN
46	JENSEN MEADOWS
47	UNKNOWN
48	POSTON
49	LITTLE PROSPECT
50	UNKNOWN
51	LONG DRAW
52	UNKNOWN
53	UNKNOWN
54	UNKNOWN
55	BOUNDARY
56	UNKNOWN
57	UNKNOWN
58	ERRAMOUSPE
59	UNKNOWN
60	UNKNOWN
61	UNKNOWN
62	RESERVOIR
63	SUBLETTE
64	SPICER GROUP
65	SPICER GROUP
66	SPICER GROUP
67	EIGHTEEN MILE
68	SPICER GROUP

USFS ALLOTMENTS

NUMBER	**ALLOTMENT NAME**
03110	TAYO
07010	SILVER CREEK
07015	BLUCHER CREEK
07016	BOUNDARY CREEK
07017	BUNION CREEK
07019	CROWS NEST
07020	DADS LAKE
07022	EAST SQUAW CREEK
07024	IRISH CANYON
07025	LAMREAUX CANYON
07027	LITTLE SANDY
07028	LOWER DUTCH JOE
07031	MUDDY CANYON
07032	MUDDY RIDGE
07040	SOUTH TEMPLE CREEK
07042	UPPER DUTCH JOE
07043	WASHAKIE-FRANCIS LAKE
07044	WEST SQUAW CREEK

SEGMENT 5

BLM ALLOTMENTS

NUMBER	ALLOTMENT NAME
1	N LABARGE COM
2	SOUTH LABARGE CO
3	YOSE IND
4	BONDURANT INDIV
5	EUBANK
	LABARGE
6	LABARGE CR RANCH
7	UNKNOWN
8	UNKNOWN
9	FONTENELLE MDW IND
10	FIGURE FOUR
11	EIGHTEEN MILE
12	UNKNOWN
13	LOMBARD
14	UNKNOWN
15	SLATE CREEK
16	SEEDSKADEE
17	GRAHAM
18	SEEDSKADEE
19	GRANGER LEAS
20	COW HOLLOW
21	OPAL

SEGMENT 6

BLM ALLOTMENTS

NUMBER	ALLOTMENT NAME
1	LITTLE SANDY
2	LITTLE PROSPECT
3	RESERVOIR
4	PACIFIC CREEK
5	SUBLETTE
6	EIGHTEEN MILE
7	SPICER GROUP
8	DEWEY PLACE
9	UNKNOWN
10	BIG SANDY
11	EDEN PROJECT
12	PULLEY PLACE
13	EATON PLACE
14	UNKNOWN
15	MIDDLE HAY PLACE
16	HIGHWAY-GASSON
17	SANDS
18	UNKNOWN
19	LOMBARD
20	UNKNOWN
21	UNKNOWN
22	UNKNOWN
23	UNKNOWN
24	UNKNOWN
25	UNKNOWN
26	UNKNOWN
27	UNKNOWN

APPENDIX II: EPIDEMIOLOGICAL RISK MODEL PARAMETERS

Table II.1. Variable Definitions and Descriptive Statistics.

Categorical Predictors					
Feature	Method of Measurement		Data Source	Majority (Min, Max)	
Aspect	Majority aspect				
	Original Values	**New Category**			
	flat	0	Calculated from 30m NED	2 (1, 4)	
	45-134º	2			
	135-224º	3			
	225-314º	4			
	all other values	1			
	Majority aspect south-facing (1) or not (0)		Calculated from 30m NED	0 (0,1)	0.22, 0.42 (0, 1)
Land cover (veg type)	Majority reclassified 30-m NLCD land cover			1 (1,2)	
	Original Values	**New Category**			
	Open Water, Perennial Snow/Ice, Developed, Barren Land,	Short			

	Herbaceous, Hay/Pasture, Cultivated Crops, Emergent Herbaceous Wetlands		
	Deciduous Forest, Evergreen Forest, Mixed Forest, Woody Wetlands Tall		
Wolf predation pressure	Maximum probability of wolves in cattle herd polygon (probability 0-1)	WYNDD wolf occupancy predictive model	0, (0,1)
Proximity to Feedground	Within 25km feedground (0,1)	Feedground point data (WGFD)	0, (0,1)
Continuous Predictors			
Feature	Method of measurement	Data Source	Mean, StDev (Min, Max)
Elevation	Mean[1] elevation (meters)	30m^2 National	2042.54, , 155.83

		Elevation Dataset (NED) (http://ned.usgs.gov/)	(1787.39, 2356.79)
Slope	Mean slope (degrees)	Calculated from 30m NED	2.64, 2.31 (0.18, 11.20)
Snowpack	Mean winter precipitation (Nov-May[3]) (inches)	PRISM http://www.prism.oregonstate.edu/products/matrix.phtml	1.11, 0.48 (0.64, 2.20)
Predation Pressure	Mean distance to forest (meters)		1974.58, 2618.26 (59.95, 10412.13)
	Mean hunter density in respective hunt area (hunters per km^2)	WGFD hunt area boundaries and WGFD harvest reports	0.53, 0.30 (0.05, 0.99)
Proximity to feedground	Mean Euclidian distance to feedground (meters)	WGFD feedground point location data	38450.76, 27434.33 (4132.90, 129641.80)
	Mean cost-distance to feedground	Calculated from WGFD feedground point location data and slope	32918.53, 31133.28 (6178.10, 111054.00)
Roads	Mean road density in cattle herd polygon (roads/km^2)	BLM road dataset http://www.blm.gov/	1.18, 0.84 (0.02, 3.39)

		wy/st/en/resources/public_room/gis/datagis.html	
	Mean Euclidian distance to major road (meters)	Major roads of Wyoming at 1:100,000 http://wygl.wygisc.org/wygeolib/catalog/main/home.page	975.29, 1283.761 (15.00, 7064.64)

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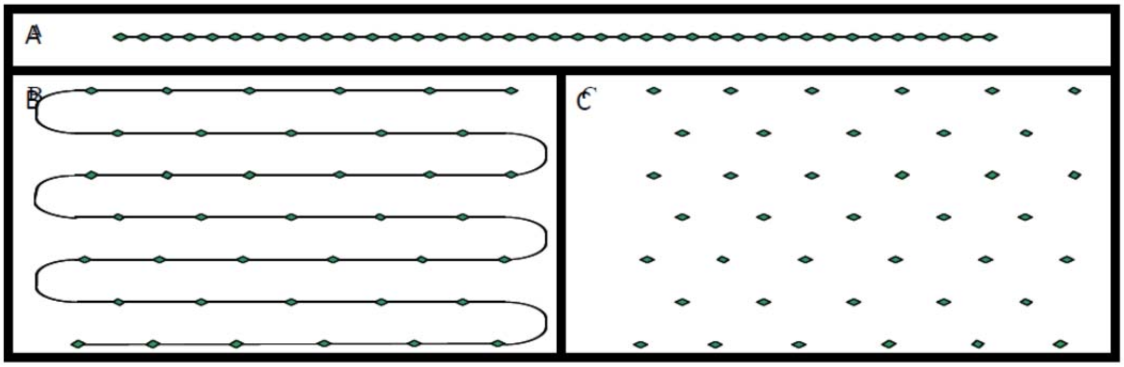
[1] Median would be the ideal measure for many of these variables, however, ArcMap 10 did not offer this as an option when calculating zonal statistics. Because calculating by hand would be computer-power and time-prohibitive, mean was used instead.

[2] 30m resolution was used throughout the analysis to ensure compatibility of reference layers with small size of some producer winter polygons.

APPENDIX III: LOW-DENSITY FEEDING ASSUMPTIONS AND BUDGET

On most feedgrounds, managers use a team of two draft horses and a sleigh to feed elk seven days a week from late November to mid-April (WGFD 2004). The WGFD has listed a number of best management practices, including feeding on clean snow and encouraging the presence of scavengers, which help clean up fetuses. In addition, switching from alfalfa to grass hay encourages elk to forage off feedgrounds earlier in the spring, and during mild winters at low elevation feedgrounds (WGFD 2004). For example, the WGFD believes switching from alfalfa to grass hay has encouraged the elk at Bench Corral Feedground to forage more extensively on native winter range (WGFD 2004). Low-density feeding spreads hay into multiple rows to discourage elk from browsing along the same line of hay. Below is a diagram of feedline patterns from the Big Piney Herd Unit Job Completion report, 2011 (WGFD 2011).

Figure III.1. Illustration of feedline (A) and low-density feeding (B & C). Dots represent ~10 lbs of hay placed at 1-m spacing (A) and 10-m spacing with 5m row spacing (B). Solid lines connecting dots depict potential feeding routes (A & B). (Source: WGFD 2011)



Tractor and Feeding Implement

Switching from a team and sleigh to a tractor and feeding implement would require purchasing equipment. In addition, due to the cold temperatures in the GYA, the diesel tractor would require an engine block heater or CATZ heater to warm the engine and enable it to start on most winter mornings. A 2000 watt generator would be necessary to power the type of heater necessary to warm an 80+ horsepower (HP) engine (VanValkenburg personal communication 2013). In fact, the two feedgrounds that use a tractor and bale processor each have a generator on site. On cold mornings it can take between 30 minutes and an hour of pre-warming the engine to start the tractor (Maichek personal communication 2012).

The price of a generator was determined by averaging the prices of five gas generators found online from Generator Factory Outlet, Power Equipment Plus, Sears and other distributors. An annualized cost for generator ownership was determined by dividing the average price of generators by the economic lifespan of a generator (10 years). The Sportsman 2000 Peak Watt Portable Generator uses 0.15 gallons/ hour, which is the assumed generator gas consumption. Newer tractors can start at temperatures above 10 degrees Fahrenheit without an engine block or CATZ heater (VanValkenburg personal communication 2013). Average low temperatures for Pinedale are below 10 degrees Fahrenheit between the middle of November and the beginning of April (Western Region Climate Center, 2013), so the tractors will need plugged in 135 out of 150 feeding days, for approximately 30 minutes each day. Pinedale 2010 gas prices in Pinedale were $2.69 per gallon (Pinedale Online, 2013).

Implement and tractor prices came from TractorHouse.com, which primarily sells used equipment. When looking for tractors, only tractors with a minimum of 80 horsepower, four wheel drive and no more than 2000 hours of use were included. I found five tractors from New Holland, Massey Ferguson and John Deere, which met these requirements (TractorHouse.com 2012). The make years ranged from 2006 to 2011, with mileage ranging from 99 hours to 1700 hours. The prices ranged from $43,909 to $38,127. Average and median costs were similar at $40,116 and $38,851 respectively. Annual depreciation is based off the average.

The extension bulletin “Estimating Farm Machinery Costs” by William Edwards at Iowa State University was used to estimate depreciation for the tractor. This bulletin was chosen because his depreciation estimates were specific to the equipment type. In addition, he provided valuable information on the costs of ownership for equipment including expected maintenance and repair costs. However, for equipment that wasn’t listed in his bulletin, Cross and Perry’s (1995) remaining value formulas were used. According to Wu and Perry (2004), these were the most comprehensive estimates published as of 2004. They have been adopted by the American Society of Agricultural Engineers as standards for farm machinery depreciation (Wu and Perry 2004).

Wu and Perry (2004) found the Box-Cox and Double Square Root (DSR) models most accurately describe depreciation on farm equipment. However, these models use information not readily available for our applications such as Net Farm Income as a proxy for the current agricultural economy. Therefore, for these purposes, Cross and Perry (1995) serve as a good comparison to Edwards for the Snow Cat, and provide a good remaining value formula for the hay feeding implement.

Edwards (2009) repair and maintenance estimates were based on the new equipment price. Therefore, the new price was derived from the purchase price using Edwards (2009) depreciation estimates. The average cost of a new tractor in 2010 was $62,277.88 while the median price was $60,652.17. According to Edwards (2009), 15 years is good economic lifespan for a tractor while 10 to 12 years represents the economic life of most other machinery. The average tractor age was 3 years, so our theoretical tractor is assumed to be bought at three years old and sold 12 years later for a salvage value of 29% of new value. Therefore the cost of owning the tractor for 12 years is the difference between purchase and salvage value plus maintenance and fuel costs.

It is assumed that the tractor is used only during the feeding season, or used lightly the rest of the year. Insurance costs are estimated at 0.5% of purchase price per year (Edwards 2009). We expect to use the tractor 348 hours per year for traditional feeding or 522 hours per year for low-density feeding resulting in cumulative total hours of 4176 hours for traditional feeding and 6264 hours for low-density feeding. Expected repairs and maintenance for these numbers of cumulative hours are 5% and 11% respectively.

Average hourly fuel consumption can be estimated by multiplying 0.044 by maximum Power Take Off (PTO) HP (Edwards 2009). The tractor would be at least 80 HP, but may be as a high as 95 HP. An 85 HP tractor is assumed, which would use 3.75 gallons of fuel per hour. Traditional feeding takes 2 hours for 500 elk, with low-density feeding requiring an extra hour (Maichek personal communication 2012). However, there are an average of 580 elk on each feedground. Assuming feeding time is proportional to elk numbers, traditional feeding should require 2.3 hours and low-density feeding, 3.5 hours.

Feeding occurs between mid-November and mid-April for an estimated 5 months or 150 days. Off road diesel should be allowed for feeding use. According to the U.S. Energy Information Administration, these prices are not publicly listed but can be determined by subtracting federal and state excise taxes, which are around 12%. According to Pinedale Online (2013) diesel prices were $2.96/gallon in 2010, so off-road prices would be $2.60/gallon. Lubrication costs are expected to be 15% of total fuel costs (Edwards 2009).

A similar method was used to determine costs for Snow-Cats and hay feeding implements. Cross and Perry’s (1995) formula was used for the feeding implements, while both Cross and Perry’s (1995) estimates and Edwards (2009) estimates were used for the Snow-Cat. Neither Snow-Cats nor feeding implements, or close substitutes of these equipment types were listed in Edwards (2009) bulletin. For large machinery, he lists tractors and combine/forage harvesters. Combines are much more complex than a Snow Cat with fast moving parts, and therefore depreciate much faster than a Snow Cat. Depreciation rates are closer to a tractor's depreciation rates, so a 150+ HP tractor depreciation factor was used. Because a 500 HP Snow-Cat is different from a tractor, both Edward's (2009) and Cross and Perry's (1995) methods are used in order to check each other. Snow-Cat costs came from Rocky Mountain Snow Cats company. Five listings for BR 350 Snow Cats were used; they ranged in year from 2005 to 2007 and ranged in price (in terms of 2010 prices) from \$138,481 to \$154,268, with an average price of \$145,114, and a median price of \$142,328.

Cross and Perry (1995) provided the following formula to estimate remaining value on machinery: $RV = [1.18985 - 0.22231 * Age^{0.35} - 0.00766HPY^{\wedge}0.39]^{2.22}$ where the Age is the age of the machinery and HPY is hours used per year. New Value, Remaining Value, and Salvage Value for the Snow-Cat were each calculated using both Edward's (2009) estimates and Cross and Perry's (1995) formulas. Both the new value and the remaining value at purchase only varied an average of about 3% between the methods. The salvage value varied an average of 13%. Edwards (2009) estimates were chosen for budget.

Fuel consumption for the snow cat can be estimated with the same formula used for diesel tractors: Hourly Fuel consumption =0.044*maximum horse power (Edwards 2009). The BR 350 has an hourly fuel use of 15.4 gallons per hour. Hours on the Snow-Cat are assumed to include packing down a trail every 4 days, while each snow packing trip is assumed to take 75% of feeding time. Total Snow-Cat hours would then be 18.75% of feeding hours. Lubrication costs are expected to be 15% of fuel costs (Edwards 2009).

Feeding implement sales from Tractorhouse.com provided an average price estimate of $22,305 in 2010 terms for a lightly used two year old bale feeder. A Cross and Perry (1995) formula was used to estimate both the new list price and the salvage value. A bale feeder depreciation formula wasn't listed, so a manure spreader depreciation formula was used because there is a similar level of complexity between the two implements. The remaining value formula is given by: $RV = [1.29956 - 0.45113Age^{0.25}]$^2.22. The implement is assumed to last 12 years, or 10 years after purchase. Maintenance costs are extremely high for hay feeding implements because of the high number of rapidly moving parts. The number of hours the feeder is used is assumed to be 70% of tractor hours, while 30% of the tractor driving time is assumed to be travel time between the haystack and feeding area. According to Edwards (2009), a manure spreader will require 47% of its original purchase price in repair/maintenance costs after 2000 hours, but he does not list expected repair costs for over 2000 accumulated hours (Edwards, 2009). To estimate repairs for the 2497 hours and 3745 hours expected for traditional feeding and low-density feeding respectively, the repair costs were scaled up using a ratio of costs expected per hour of use.

Team and Sleigh

Draft horse prices were found on DraftsforSale.com (2012). Only teams that are broke to pull and no older than 5 years were considered. The average price in 2010 terms was $3731. The team is assumed to work from age five until age twenty, for a useful lifespan of 15 years.

For feed cost calculation, the year is divided into two seasons where: 1) horses are not working and grazing on pasture and 2) horses need to be fed hay and grain while they are working. The horses graze from mid-May (May 15) through October (October 30) or 5 ½ months. According to Wyoming Agricultural Statistics (2011), 2010 grazing rates on nonirrigated private pasture land were $16.60 per AUM. The animal unit equivalent for a draft horse is 2 AUs, and a team would constitute 4 AUs. Therefore, the horses would use 22 AUM's of grazing per year, for a cost of $487 for summer grazing. Horses need hay while not on pasture, and need additional concentrated feed while working. A horse doing moderate work (2 to 4 hours per day) needs to eat 1.5% to 2.5% of their weight per day. The average Percheron weighs 1900 lbs., while the average Belgian weighs 2000 lbs (Washington State University, 2008). It is assumed that each horse weighs 2000 lbs. A horse needs to eat 2% of their body weight or 40lbs. each day (Washington State University, 2008). They also need 7 lbs. of energy such as grain per day (Washington State University, 2008). Therefore the horse will consume 33 lbs. of hay and 7 lbs. of grain each day while working.

A mixture of Corn, Oats, and Barley (COB) is common and nutritious feed that is widely available. I averaged prices for three brands of COB or sweet feed from C-A-L's ranch store in Idaho Falls and Murdoch's in Laramie. Feeds included bulk sweet feed from C-A-L's, Purina Sweet Feed, Rocky Mountain Sweet Mix, and Stack and Stable Sweet Feed from Murdoch's. Prices ranged from $0.22 per lb. to $0.26 per lb. with an average and median 2010 price of $0.19 per lb. The Wyoming Agricultural Statistics book (2011) shows 2010 hay prices at $85.00/ ton, while 2011 prices were $120.00/ton. Adjusting 2011 prices to 2010 provides a price $93.00/ton which is used in this budget. Horses are assumed to be fed good quality hay but not alfalfa, which has a premium price.

Additional team and sleigh costs include a feed sleigh, a double tree, two single trees and two harnesses. All prices come from My Draft Horse Super Store (2012). The harnesses are assumed to last 30 years. According to Dave Hyde at the Jackson WGFD office, sleighs have been obtained by the WGFD by buying metal sleigh bobs from a business in Driggs, Idaho for between $2,200.00 and $2,400.00 and adding on a wooden rack for $1000. The old wooden bobs had a lifespan of around 50 years, but the new metal ones will last for much longer (Hyde, pers. comm. 2013). An economic lifespan of 100 years is assumed, with the rack being replaced every 20 years due to rotten wood. It is possible in deep snow country a Snow-Cat would be needed to help pack down the snow every few days for the horses. If this is the case, costs for using the Snow Cat would be the same as when used with a tractor and feeding implement. Generally, the WGFD uses their own horses to feed, but rent the use of horses from the feeders in some circumstances. In those cases, horse rental per day is $3.00 per horse. This possibility is not included in the budget.

Labor

Hitching and harnessing, and unhitching and unharnessing a team takes around 30 minutes, the same time that is required to warm up a tractor. On a ranch, warming up a tractor would not be considered a labor cost because there is no work involved with warming a tractor except plugging it in. However, given that feedgrounds are not immediately adjacent to feeder's homes, they have to travel to the feedground each morning, and it wouldn't be practical to leave the feedground after plugging in the tractor to return a short time later. Therefore, the feeder has to wait 30 minutes until the tractor engine is warm before starting the tractor and feeding elk. Therefore, tractor and horse labor costs are assumed to be the same. As is stated above, feeding 580 elk is assumed to take 2.3 hours for traditional feeding and 3.5 hours for low-density feeding, so using low-density feeding requires higher labor costs than traditional feeding. In addition, hiring an extra person is assumed to double the labor cost. Below is a table of the costs of a variety of methods of feeding (Table III.1).

Table III.1. Low-density feeding costs for various approaches.

Feeding approach	**Labor cost**	**Cost of all other inputs**	**Total annual cost for a single feedground (change in cost from traditional)**
Trad. Feeding-Horse	4156	2713	**6869 (+0)**
Trad. Feeding-Tractor	4156	32826	**36983 (+0)**
Trad. Feeding-Snow-Cat	779	8343	**9123 (+0)**
LD Feeding-Horse (using extra time of original person)	6235	2713	**8947 (+2078)**
LD Feeding-Tractor (using extra time of original person)	6235	48789	**55023 (+18040)**
LD Feeding-Snow-Cat (using extra time of original person)	7404	10240	**17644 (+8521)**
LD Feeding-Horse (using extra horse)	4156	9496	**13652 (+6783)**
LD Feeding-Horse (using extra person)	12469	2713	**15182 (+8313)**

Feeding with a team and sleigh is far less costly than feeding with a tractor, for both traditional and low-density feeding. Low-density feeding is more costly than traditional feeding, while using a Snow-Cat increases the costs of any type of feeding. However, if tractors are used in multiple seasons the per hour cost of their use, including cost of feeding would decrease. Draft horses are rarely used during the summer, but if they did work during the summer, their cost per hour would decrease as well. If low-density feeding has the potential to decrease seroprevalence by 70%, it may be a cost effective way to decrease seroprevalence. Elk feed was not considered in these budgets because the funding for the hay is already committed, and should not change with the method of feeding. See Boroff's forthcoming thesis for a more detailed description and budget for low-density feeding.

APPENDIX IV: STRAIN 19 VACCINATION ASSUMPTIONS AND BUDGET

Labor and Number of Elk Vaccinated

The WGFD pays feeders a flat rate of $350 per year to vaccinate elk at their respective feedground plus $0.75 for each additional elk vaccinated, beyond the first 200 (Scurlock personal communication 2012). The number of elk vaccinated varies from year-to-year due to weather conditions that influence the number of elk using feedgrounds. To better understand the variability in the cost of hiring feeders to administer the brucellosis vaccine, the number of elk vaccinated since the program began in 1985 and 2010 were obtained from the Job Completion Reports (JCRs) (WGFD 2011).

Only the Pinedale region feedgrounds were included in the cost estimates because the WGFD's Pinedale Office was able to provide sufficient data and answer questions about elk in this region. The Pinedale region includes the Big Piney, Pinedale, Upper Green and Hoback herd units. Jackson region feedgrounds were excluded from cost estimates because the WGFD JCRs for that region did not specify the number of years in which feeding and vaccinating were skipped. There was insufficient information to correctly calculate vaccination costs for the Jackson Region.

Two sets of costs were calculated: (1) all feedgrounds in the Pinedale region, and (2) only Muddy, Scab and Fall Creek feedgrounds within the Pinedale herd unit (PHU). The PHU was calculated separately from other herd units to facilitate comparison with Test-and-slaughter and other management strategies. In addition, vaccination costs in the PHU may differ from other herd units because the PHU is close to the regional office in Pinedale.

While the vaccination program was started in 1985, feedgrounds were gradually added to it through 1997. During the first year (or sometimes two years) of the program, all females and juveniles were vaccinated. In following years, only juveniles were vaccinated. However, some years, when snow levels are low, elk may not come down to a feedground due to available forage off the feedground. After a year or more without feeding, all cows and juveniles are again vaccinated at that feedground, to make up for years in which no vaccination occurred. The JCRs provide information about the year in which vaccination was started at each feedground, and the number of years vaccination was skipped at each feedground. The JCRs also provide the total number of vaccines given to both juveniles and adult females over the years. Total vaccinations given divided by the number of years vaccination occurred provides an average number of elk vaccinated per year.

However, recent JCRs did not include vaccination numbers for the Pinedale Herd unit because vaccination was stopped after 2004, in preparation for the Test-and-slaughter program. The Wyoming Elk Feedgrounds document provides the total number of vaccinations given at the Pinedale feedgrounds of Muddy Creek, Fall Creek and Scab Creek since the start of the program (WGFD, 2004). The JCR indicates that between 80% and 100% of elk at a feedground are normally vaccinated, so 90% of adult female elk at a feedground were assumed to be vaccinated in the first years of the project at each feedground. Estimated yearly PHU vaccine requirements are 770, while 2,144 vaccines are required yearly for all feedgrounds in the Pinedale region.

In addition to labor costs of feeders, there are labor costs for WGFD employees. WGFD personnel assist new feeders in vaccinating elk and may also vaccinate elk themselves. For example, they have vaccinated elk at Finnegan, Soda Lake and Bench Corral feedground. Brandon Scurlock estimates that he, Eric Maichek and Jared Rogerson spend 17 or 18 days vaccinating each year (Scurlock personal communication 2012). In addition, WGFD personnel spend three to four days preparing and organizing for vaccination (Scurlock personal communication 2012). Wildlife biologist wages were obtained for Wyoming from Bureau of Labor Statistics (2012).

Transportation

The Research and Innovative Technology Administration (RITA) estimates transportation costs as $0.59 per mile (RITA 2010; Roberts, 2011). Mileage from the WGFD's Pinedale Field Office to each feedground was found using Google Earth. Total, average and median distances were calculated for both PHU feedgrounds and regional feedgrounds.

Vaccines

Elk vaccines are given at feedgrounds via biobullets remotely deliverd from air-powered rifles from a range up to 40 yards. Biobullets are small capsules of hydroxypropyl cellulose containing strain 19 vaccine. They dissolve in muscle over time, releasing the vaccine. Strain 19 is only produced at the National Vet Services Laboratory (NVSL) in Ames, Iowa, where they package it into biobullets for the WGFD to use in their elk vaccination program. The laboratory determined costs to be $5.98 per biobullet when they produce 2,834 biobullets as they did in 2011 (Carter personal communication 2012). For this budget, it is assumed that the cost wouldn't differ significantly for different numbers of biobullets produced.

Equipment

Biobullets are only 6mm long. In order to ship the 2144 biobullets necessary for vaccinating all regional feedgrounds, a 24" by 24" x 10" box is needed, which would cost $30.00. To ship the 770 biobullets which would be necessary for vaccinating the Pinedale Herd Unit a 11" x 8.5" x 5.5" box would be required, for a price of $12.53 (USPS 2012). The WGFD purchases the actual bullets, clips, tape and clip sleeves, which are used for holding loaded clips. They send these materials to NVSL, which then produces complete biobullets. The WGFD buys these materials in bulk and uses them for multiple years. They bought empty bullets and clip sleeves in 2008, and empty clips in 2007. They also use a tape specially developed for them by 3M to seal each side of the clips after bullets are inserted (Scurlock personal communication 2012).

The entire ballistic system used to deliver the vaccine to elk includes an air rifle, rifle hose regulator, an air tank, backpack and gun sleeve. The purchase price of this package is $1950, and is expected to last 15 to 20 years (Shwiff personal communication 2012). The WGFD bought 25 guns but currently has 21 or 22 in working condition, or about one per feedground (Maichek personal communication 2012). Air tanks are refillable so there is not an extra cost for the air discharged from each shot. A summary of estimated costs is presented below (Table IV.1).

Table IV.1: Strain-19 vaccination costs.

Item Description	**Pinedale Herd Unit FGs**	**Per FG (PHU)**	**All FGs**	**Per FG (All)**
Total Elk Vaccinated	769	256	2144	195
Feeground Manager Labor	$1,153	$384	$4,016	$365
WGFD Employee Labor	$1,261	$420	$4,117	$374
Annualized Gun Cost	$303	$101	$1,109	$101
Other Equipment and Biobullets	$4,724	$1,575	$13,166	$1,197
Transportation Cost	$125	$42	$620	$56
Total Yearly Costs	**$7,565**	**$2,522**	**$23,029**	**$2,094**

The number of elk at a feedground determines the total cost of vaccinating at that feedground, and also affects the average cost of vaccinating an individual elk. As the number of elk vaccinated increases, the total cost of vaccination may increase, but the average cost per animal will decrease because not all vaccination costs vary with elk numbers. Although transportation costs are lower for the Pinedale Herd Unit feedgrounds, the larger elk population increased costs for the PHU over regional feedground costs. See Boroff's forthcoming thesis for a more detailed description and budget for Strain 19 vaccination.

APPENDIX V: TEST-AND- SLAUGHTER ASSUMPTIONS AND BUDGET

At each feedground, the WGFD had previously built elk traps to conduct regular seroprevalence tests. However, these traps were only intended to capture enough elk to constitute a sufficient sample size (less than 100 elk) to obtain statistically significant results. In contrast, test-and-slaughter requires capturing the majority of the feedground elk to be effective. Therefore, larger traps were built to accommodate larger elk numbers. An additional requirement was that all new traps be portable, as required by the federal land agencies where feedgrounds are located (Scurlock *et al*. 2010). The traps cost $100,010 each and represent the only multi-year cost for test-and-slaughter; they were paid for over two years and are expected to last 15 years (Scurlock personal communication 2012). The WGFD spent $151,218.00 the first year and $148,812.00 the second year (Scurlock *et al*. 2010) for the traps.

In addition to new traps, test-and-slaughter required extensive snow and ice removal, both from the traps and on roads into feedgrounds. Trap snow removal was required to prevent elk from walking over trap walls on snow banks, while plowed roads were necessary to allow a truck and trailer to remove seropositive elk (Scurlock *et al*. 2010). The WGFD kept thorough cost records, but did not account for road plowing costs, because Sublette County provided these costs free of charge. Before the county offered to plow the roads, the WGFD considered contracting out the services. A private company quoted a price of $30,000 to be on call to open up roads for the three weeks each winter for when trapping was planned (Scurlock pers. comm. 2012).

The actual cost to the county was unlikely to be $30,000 dollars, so the costs they incurred were estimated as well. Distances from Pinedale to each feedground were measured using Google Earth. It is 24 miles to the Scab Creek feedground, 10 miles to the Fall Creek feedground and 31 miles to the Muddy Creek feedground. However, the county plows part of that distance in their normal routes so the additional plowing distance would be much shorter. It is 3.6 miles from Big Sandy Elkhorn road (SR 353) to Muddy Creek, 8 miles from SR 353 to the Scab Creek Feedground. It is 5.4 miles from the Bargerville subdivision to the Fall Creek Feedground or 10.1 miles from the feedground to US 191 north of Boulder. A motor grader or Dozer can plow approximately three miles in an hour and the charge rate for a motor grader or Dozer is around $125 per hour (VanValkenburg personal communication 2013). With these assumptions, the cost of plowing the road to Fall Creek, Scab Creek and Muddy Creek feedgrounds would be $225, $333 and $150 respectively.

These costs are far smaller than the costs of hiring a company to be on call for an entire three week period. It is necessary to have flexibility when trapping elk, because the number of elk that enter the trap varies day by day according to elk behavior and weather conditions. Therefore, plowing personnel would need to be flexible with trapping conditions. Two separate budgets were developed for test-and-slaughter to reflect the difference in county versus private plowing costs.

It becomes difficult to assign yearly costs for a test-and-slaughter program without knowing the amount of trapping that would take place. During the five year pilot project, test-and-slaughter occurred at Muddy Creek all five years, and two years at Fall Creek and Scab Creek. In 2009, there were three test-and-slaughter events; in 2008 and 2010, there were two; in 2006 and 2007, there was only one. Due to differences in trapping event numbers, most costs are based on a “per trapping event” basis. This makes sense for most expenses, such as labor, lab costs, vehicle usage, meat processing, and travel expenses, and allows for multiple budgets given two or three trapping events per year.

Table V.1. Test-and-slaughter costs.

Budget Type	Yearly Total	Per Capture	Per Elk Bled	Per Elk Slaughtered
$30,000 Private Plowing				
2 Trapping Events	$447,196	$852	$1,411	$10,215
3 Trapping Events	$658,291	$836	$1,385	$10,025
Sublette County Plowing				
2 Trapping Events	$409,111	$779	$1,291	$9,345
3 Trapping Events	$601,164	$763	$1,265	$9,155

Yearly costs are higher with three trapping events than two, while per capture, per elk bled, and per elk slaughtered costs are less with three trapping events than two. This results from trap depreciation being spread over a larger number of animals with a larger number of trapping events. All budgets account for depreciation and maintenance of all three traps, regardless of the number of trapping events. All budgets are in 2010 dollar values. When considering future budgets for test-and-slaughter, changes in the price of goods and services needs to be considered, particularly for items that fluctuate in price such as fuel. See Boroff's forthcoming thesis for a more detailed description and budget for test-and-slaughter.