The Great Sand Dunes Ecosystem Elk and Bison Carrying Capacity Model: Description and Scenario Results

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I. Introduction

Great Sand Dunes National Park and Preserve and neighboring Baca National Wildlife Refuge is an extraordinary setting that offers a variety of opportunities for outdoor recreation and natural resource preservation. The Park and Refuge are adjacent to and abut the Sangre de Cristo Mountains in the San Luis Valley of Colorado. It is a remote and rugged area in which resource managers must balance the protection of natural resources with recreation and neighboring land uses.. The management of wild ungulates offers a challenge, as ungulates such as elk freely migrate all across public and private landscapes.

Given the need for scientific information to form the basis of a multi-agency ungulate management plan for the region, Great Sand Dunes National Park and Preserve, hereafter sometimes referred to as the Park, sought the creation of Elk and Bison Carrying Capacity Models for the Park, the Baca National Wildlife Refuge (the Refuge), the Nature Conservancy's Medano Ranch (Ranch), and surrounding federal, state and private areas in and along the Sangre de Cristo Mountains. We created a carrying capacity model for elk and a model for bison to fill that need. We developed an Elk Carrying Capacity Model (ECCM) first, and then modified it to address areas that have both elk and bison to create a Bison Carrying Capacity Model (BCCM). The base model is a landscape-scale model based on recent precedents in Wyoming (Hobbs et al. 2003) and Colorado (Wockner et al. 2009) that can provide baseline carrying capacity estimates as well as analyze possible "management scenarios" that agency partners may consider.

The ECCM is a relatively simple model. Our approach is parsimonious beginning with a simple "base model," and adding detail incrementally as it is needed to address questions unresolved by the simpler model. It uses general habitat-based management principles and ArcView GIS technology. The model is transparent, relying on input from existing information generated by local, state and federal government agencies, but then is more highly refined based on local field research. The inputs to the model include field measurements conducted by USGS and NPS staff over a multi-year research project.

II.   Habitat Sustainability

The model is designed to calculate the carrying capacity for elk and bison on the landscape given the goal of ensuring that the habitat remains sustainable for the health of the vegetation and for grazing ungulates. It promotes habitat sustainability by not allowing a large portion of the vegetation production to be consumed by ungulates. This same sustainability concept was successfully employed by the Colorado Division of Wildlife (CDOW) Habitat Partnership Program across western Colorado in its "Habitat Assessment Model" (http://www.nrel.colostate.edu/projects/habitat/) (Wockner et al. 2009).

Many factors combine to determine how much vegetation consumption can occur before a habitat is no longer sustainable. These factors include species composition, season of use, intensity of use, and prior grazing history (Coughenour 1991). The habitat sustainability levels used in our model are based on the union of practical field knowledge and review of previous work. A number of studies have been performed to assess the effects of grazing on grasslands and shrublands from various parts of the world. A review conducted by Milchunas and Lauenroth (1993) compiled 97 of these studies encompassing 276 data sets, and generated some general results for herbage consumption. In semiarid systems with a short evolutionary history of grazing, when grazed versus ungrazed plots were compared, there was a mean consumption rate of aboveground net primary production (ANPP) of 35 percent in the grazed plots. This consumption rate resulted in a moderate change in species composition from native vegetation. Holechek and Pieper (1992) show moderate grazing intensity for different semiarid range sites varies from 25 to 50 percent, with moderate grazing for sagebrush grasslands averaging between 30 and 40 percent ANPP, depending on condition.

Unlike most grazing studies that focus on the pasture or allotment scale, the habitat sustainability levels used in our model apply to an entire landscape, and encompass numerous range-site types from an elevation of 7,500 feet to over 12,000 feet, so there can be wide variation at this scale. To set a sustainable level of grazing, we created a "habitat sustainability factor" – the amount of ANPP that has to remain on the ground to ensure habitat sustainability – based on the research above, the need to allocate forage availability across the entire landscape, and our experience in applying a similar forage-based capacity model to areas throughout western Colorado (Wockner et al. 2009).

Instead of creating just one number as the "habitat sustainability factor," we also created a range with a high threshold and a low threshold, and including a midpoint, again based on our previous work in Colorado (Wockner et al. 2009). The low threshold value represents the consumption of 25% of the total ANPP, midpoint consumption equals 28.5%, and the high threshold value equates to 32% consumption of ANPP. Conversely, at the low threshold, 75% of ANPP remains ungrazed; whereas at the high threshold, 68% of ANPP remains ungrazed. At the midpoint 71.5% of ANPP remains ungrazed. Because the model leaves so much of ANPP ungrazed, the ECCM is considered to be a "conservative" model for habitat sustainability.

The low and high thresholds represent theoretical lower and upper guidelines that can be used for Park and Refuge management decisions. These thresholds are based on forage use averaged across the entire landscape. Some areas within the landscape being modeled will receive use above the threshold levels, while others will receive little or no use. The assumption within the model is that these thresholds represent sustainable usage levels based on the scale of an entire landscape.. Periodic field monitoring and management actions by trained personnel may be necessary to ensure habitat sustainability -- because our model does not capture finer scale spatial heterogeneity in resource availability, monitoring more heavily used sites would especially be prudent."

Because the model is relatively simple, it does not take into account variability in forage nutritional value, season of use, or habitat selection by ungulate species. The model merely looks at the habitat from a "raw pounds of food" perspective. More complicated models can certainly take these factors into account, but at a far greater expense of time and money. Additionally, in previous studies in the Yellowstone Ecosystem and in North Park Colorado, both simple and complex models yielded very similar results, at least in regard to ungulate stocking (Singer et al. 2004, Weisberg et al. 2002).

III. Data Input Sources for the ECCM

Gathering and processing information to create the model is one of the more difficult steps in the modeling process. Data sources need to be gathered, interpreted, manipulated and properly formatted and some new data has to be generated. There are six main data sources which drive the ECCM. These are:

A. Study Area Delineation
B. Vegetation Production Values
C. Elk Range Polygons
D. Additional Wild Ungulate Offtake from Non-Target Species Other Than Elk
E. Bison Range and Offtake
F. Livestock Offtake

Each of these will be addressed below.

A. Study Area

Resource managers in the Great Sand Dunes National Park and Preserve believe in a holistic concept of natural resource management where the Park is not an isolated landscape but fits into broader ecosystem involving other public and private land managers. Additionally, elk migrate across the landscape and had to be modeled at a broader scale than just the Park and Refuge. Managers, including Park, CDOW, and Refuge personnel, agreed to include two game management units (GMUs) for the study – units 82 and 861, an area of 830,120 acres. These two units comprise both a relatively distinct ecosystem and comprise the rough outlines of the entire migration range of the elk in question. The study area is depicted in Figure 1.

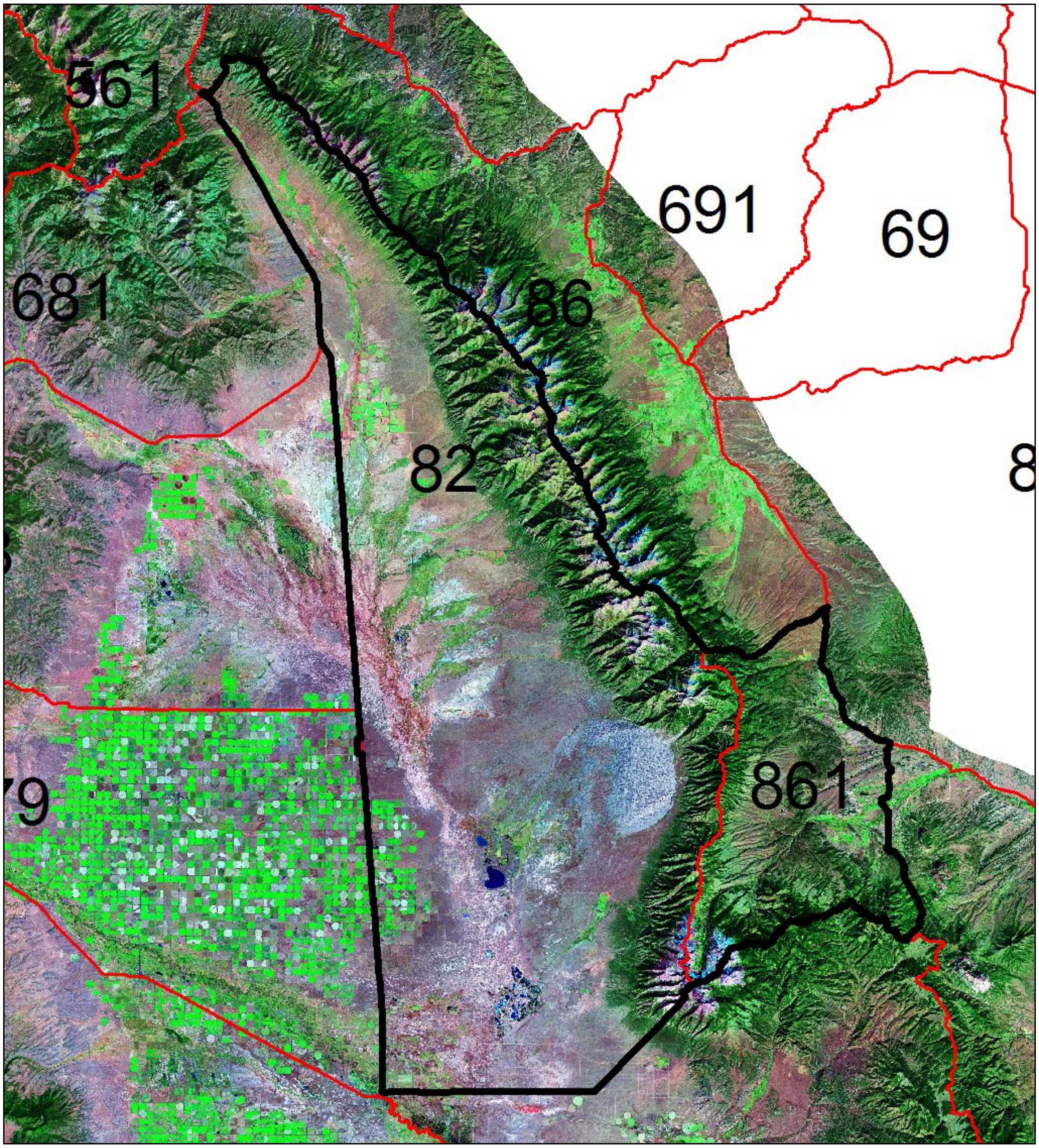

Figure 1. Study area. Red lines indicate CDOW GMUs, black lines indicate study area boundary which encompasses GMUs 82 and 861.

B. Vegetation Production Values

Vegetation production values are one of the biggest drivers in the model. Stated simply, the greater the suitable vegetation available, the more elk or bison can be sustained; the less vegetation available, the fewer elk or bison can be sustained. The technique we used to create the vegetation production map is based on sophisticated satellite mapping, land cover mapping, statistical procedures, and local field research. We created both an annual forage production map and a complete land cover map for the study area.

We used an existing high-resolution land cover map developed by cooperative group of scientists from BOR, FWS, USGS, NPS, NatureServ, and CSU (D. Salas, Bureau of Reclamation, pers. comm.). We collapsed the detailed vegetation classification from this original map into 13 vegetation types. That map included 413,287 ac, or about 50% of our entire study area. We used the Colorado Vegetation Map (CVM) version 8 (Theobald et al. 2004) to represent areas not included in the high resolution map. The vegetation classes within the CVM were relabeled to correspond to the 13 classes used in this study (Figure 2). The two maps were then merged, and CVM classification edited to improve agreement with the high-resolution map (Figure 2). Specifically, some areas identified as pastures were reclassified as wet meadows and wetlands as in the high-resolution map. The cottonwood and willow class was also greatly reduced, which appeared to be estimated in the CVM map using a distance-to-water measure that overestimated coverage relative to the high-resolution map.

We used forage production estimates derived from field measurements to estimate production in four of the 13 vegetation classes in the map (the alpine estimate included data from a study conducted in central Colorado, Walker et al. 1994). These data were insufficient for direct use in the modeling because they were sparsely distributed across the landscape, but did provide a necessary comparison to production estimates that were mapped by the National Resource Conservation Service (NRCS).

Extensive portions of the study area had NRCS forage production estimates mapped at relatively high resolution (i.e., estimated from essentially county-level soils maps, known as SSURGO data). The lowlands had SSURGO data available, with 527,549 ac or 64% of the area, mapped. Production in high elevation areas was represented using statewide coarse-scale production estimates (i.e., so called STATSGO data). All spatial surfaces were resampled to 1 acre (63.61 m square) pixels.

Using the NRCS data resulted in a dual resolution map of the study area with the lowlands mapped in high detail, and the highlands in very low detail. We sought a means to improve the resolution of forage production estimates in the high elevation portion of the study area. Forage production is known to be related to a series of physical and remotely sensed measures (e.g., aspect, land cover, greenness as measured from satellites, gross primary production). Therefore we conducted regression analyses to predict production for areas where high resolution data were not available using production estimates from the area mapped at high resolution.

In the regression analyses we calculated production estimates from 16,683 randomly located sites within the area with high resolution production estimates as the dependent data A suite of independent data included elevation, slope, aspect, land cover type, percent cover of bare ground, herbs, and trees as estimated from satellite images (MOD44 product), reflectance in GeoCover Landsat data from ca. 2000, greenness as represented in satellite normalize difference vegetation indices, and gross primary production estimates (MOD17). Tree regression failed to yield useful results, and so linear regression was used. After confirming near-normal distributions of input data, backward step-wise regression was used to create a final statistical model. This included land cover classification, elevation, slope, reflectance within GeoCover (band 3), greenness during the growing season, a tree cover estimate, and gross primary production. The final statistical model, with $< 2\%$ of the 16,683 samples excluded as outliers, explained 34% of the variation in forage production ($P<0.001$).

To approximate the nature of the SSURGO production estimates, production from the regression model was classified into categories spanning 100 lbs/ac/yr production, then passed through a majority filter, which replaced single isolated pixels of a given value with the majority of the neighboring pixels. The final map was created by merging three data layers in a hierarchical way, so that areas with values in the first layer were used rather than those in the second or third. We merged: 1) a layer that contained zero production for areas labeled Non-vegetated/Developed in our land cover map, 2) SSURGO production estimates, and 3) classified estimates from our regression analyses.

Through our research in western Colorado (Wockner et al. 2009), we found that SSURGO and STATSGO production values overestimated current production by about 20%, because these datasets are often a decade or more out of date. The differences between the production estimates in SSURGO and STATSGO are generally due to recent invasion of weedy species and other unpalatable species, reduced precipitation in recent years, and in some cases, overstocking of livestock or wild ungulates. We therefore applied a 20% downward correction to the production map by multiplying its values by 0.80, yielding the final forage production map for the study area (Figure 3).

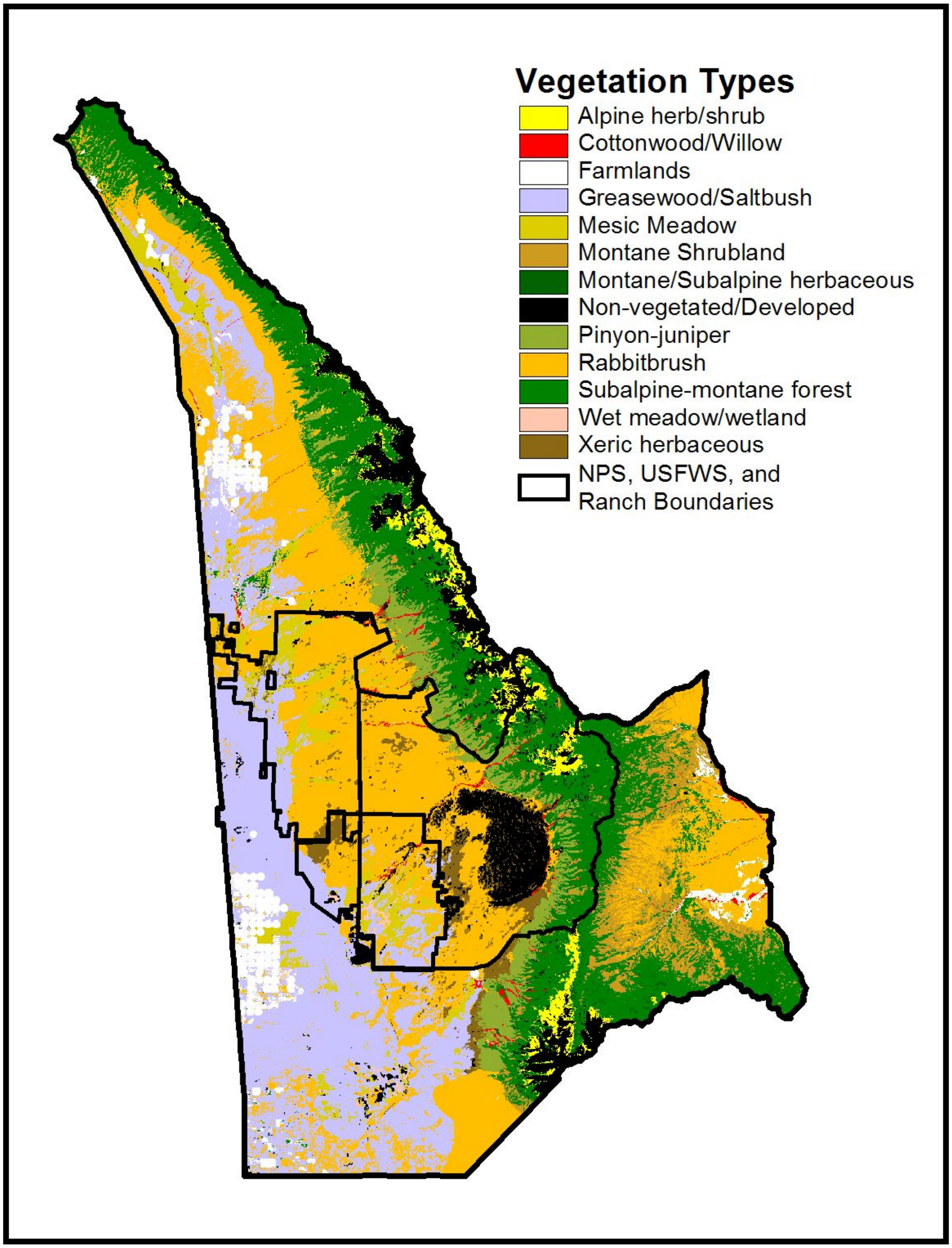

Figure 2. Vegetation map for the study area.

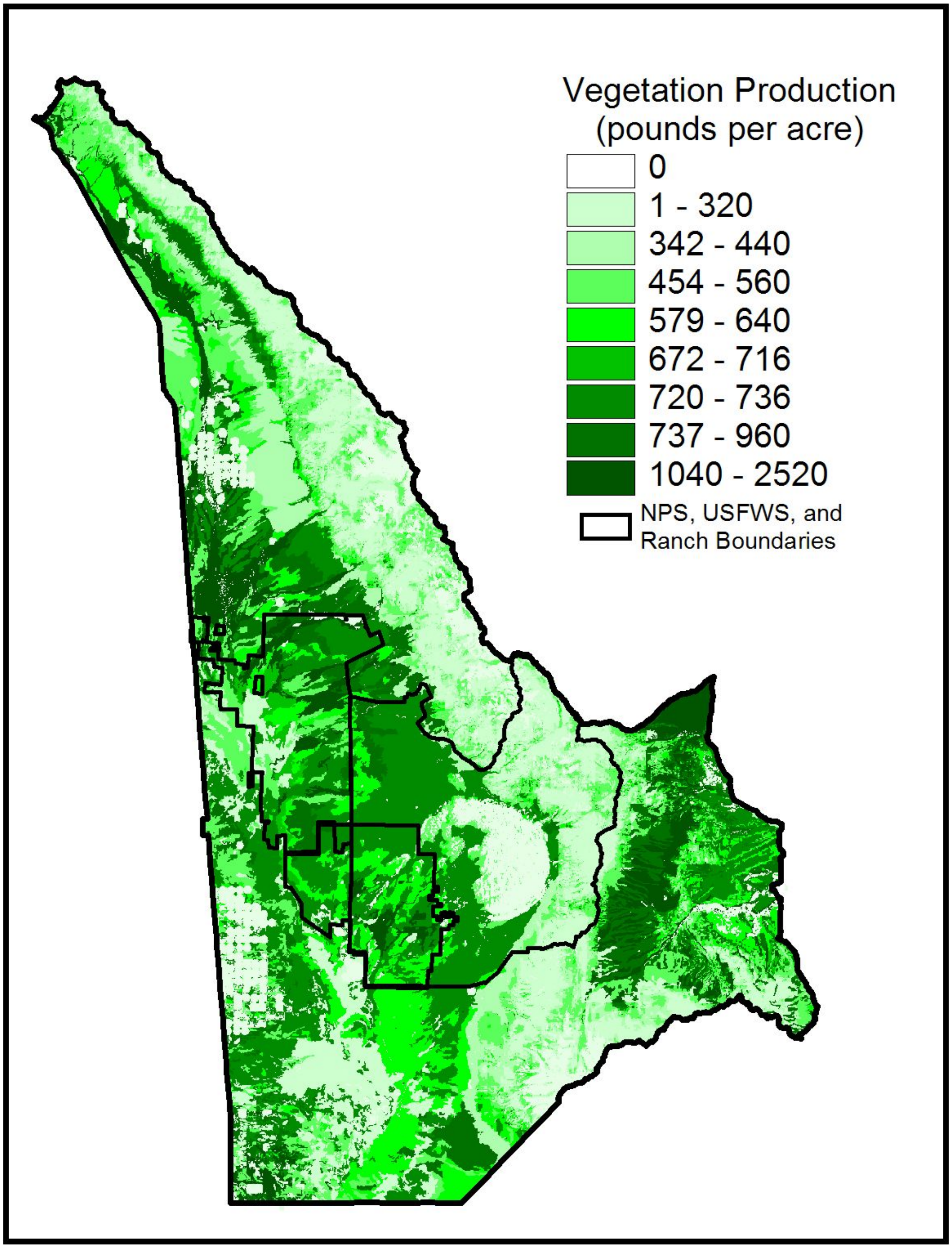

Figure 3. Vegetation production for the study area.

C. Elk Range

The elk range polygons (Figure 4) were created using data from GPS collars, aerial helicopter survey, and VHF radio collars in the study area. Individual elk locations were used to calculate 90% kernel home range estimates. Those estimates were then stacked in a GIS to yield relative density maps. Layers were created that showed all areas used by elk in those maps, and from those, the range boundary was created. Because the seasonal variability of range use was very low (there was much overlapping of range in all seasons), we merged seasonal polygons together to create one unified elk range in the study area. We emphasize that this range is not all the potentially available habitat for elk in GMUs 82 and 861, but more conservatively estimates the habitat carrying capacity for the area we know to be used by elk based on collar location and survey data. In addition, areas we did not want to make available to elk (irrigation pivots, other agriculture lands) were removed from the model by subtracting them from available forage.

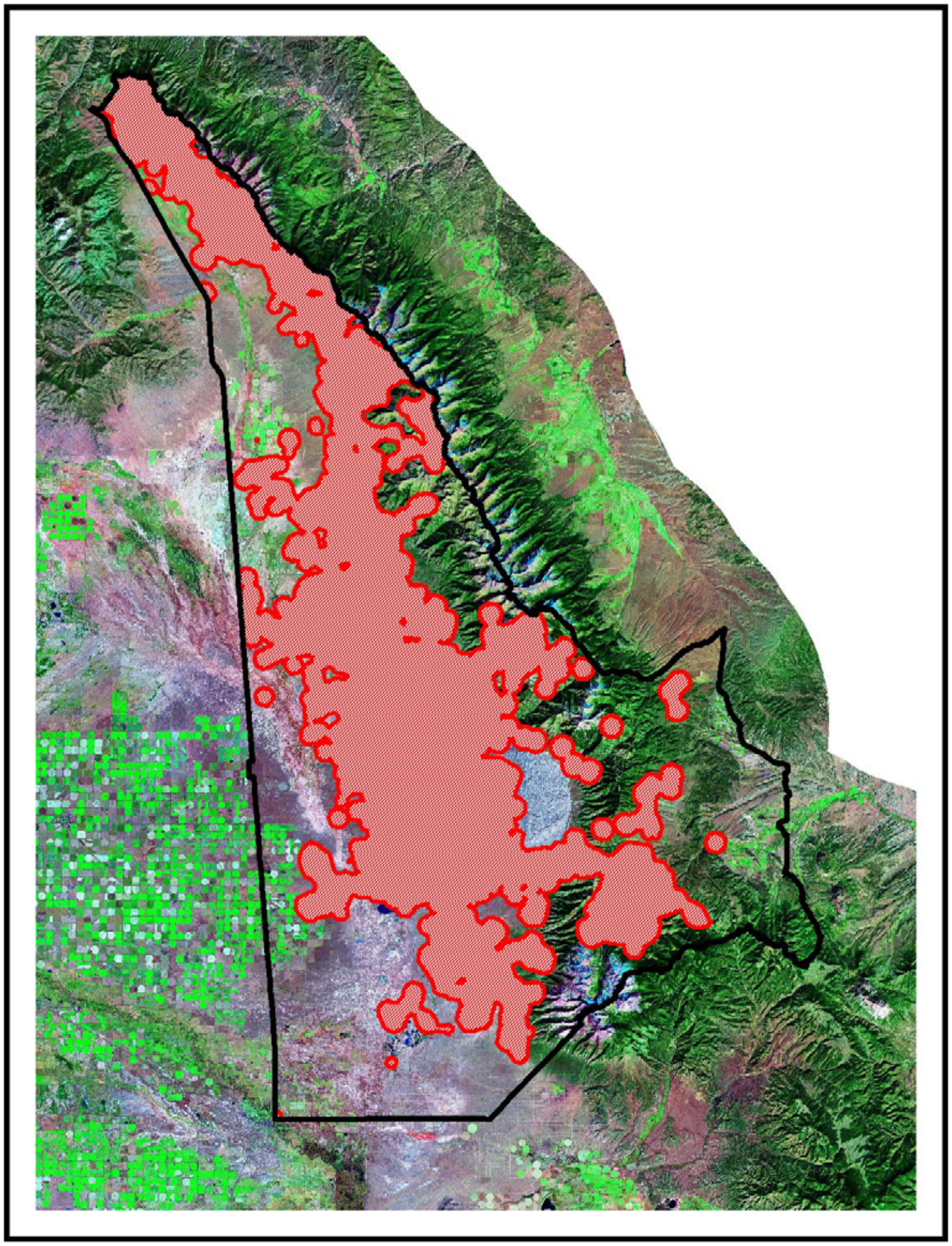

Figure 4. Elk range, comprising 395,651 acres of the study area.

D. Non-Target Wildlife Offtake

Within the study area are “non-target” wildlife, including mule deer, bighorn sheep, and pronghorn antelope. To include these animals in the ECCM, an offtake map accounting for their forage use was generated (Figure 5). The CDOW Wildlife Resource Information System (WRIS) database contains digital maps detailing the overall range and winter range for all species that fall into this category and are relevant to the scope of this modeling process. These WRIS maps, combined with estimates of current population numbers provided by the CDOW were used to generate forage offtake maps for these species. The process for generating offtake maps for one of these species is as follows:

1. Obtain the WRIS digital maps of overall range and winter range for each species from the Natural Diversity Information Source (NDIS) website (http://www.ndis.nrel.colostate.edu) or by contacting the CDOW GIS Unit.
2. Get an estimate of current population numbers from the CDOW District Wildlife Manager or from the Habitat Biologist responsible for that area.
3. Calculate the total forage demand generated by the estimated population. Table 1 below provides the average body weight estimates for the wild ungulate species used in this model (Wassink 1993). Average daily forage demand for grazing ungulates varies from 2.5 percent of body weight during active forage growth to 1.5 percent during forage dormancy (Holechek and Pieper 1992), with an average of 2 percent.

Table 1. Sample Average Body Weights for Wild Ungulates

Wild Ungulate	Average Body Weight per Individual
Pronghorn Antelope	100 lbs
Bighorn Sheep	200 lbs
Mule Deer	150 lbs

4. The forage demand generated in step 3 now needs to be allocated across the landscape. To do this for mule deer, for example, the demand created by the entire population is distributed equally across all of the land within the overall range for the six summer months and then across only the land in the winter range for six months – there are approximately 3,230 deer in the study area, as reported by CDOW (CDOW 2008). For bighorn sheep and pronghorn antelope, the population was more simply distributed across the overall range for 12 months to reflect their seasonal distribution.

The non-target wildlife offtake map is in Figure 5.

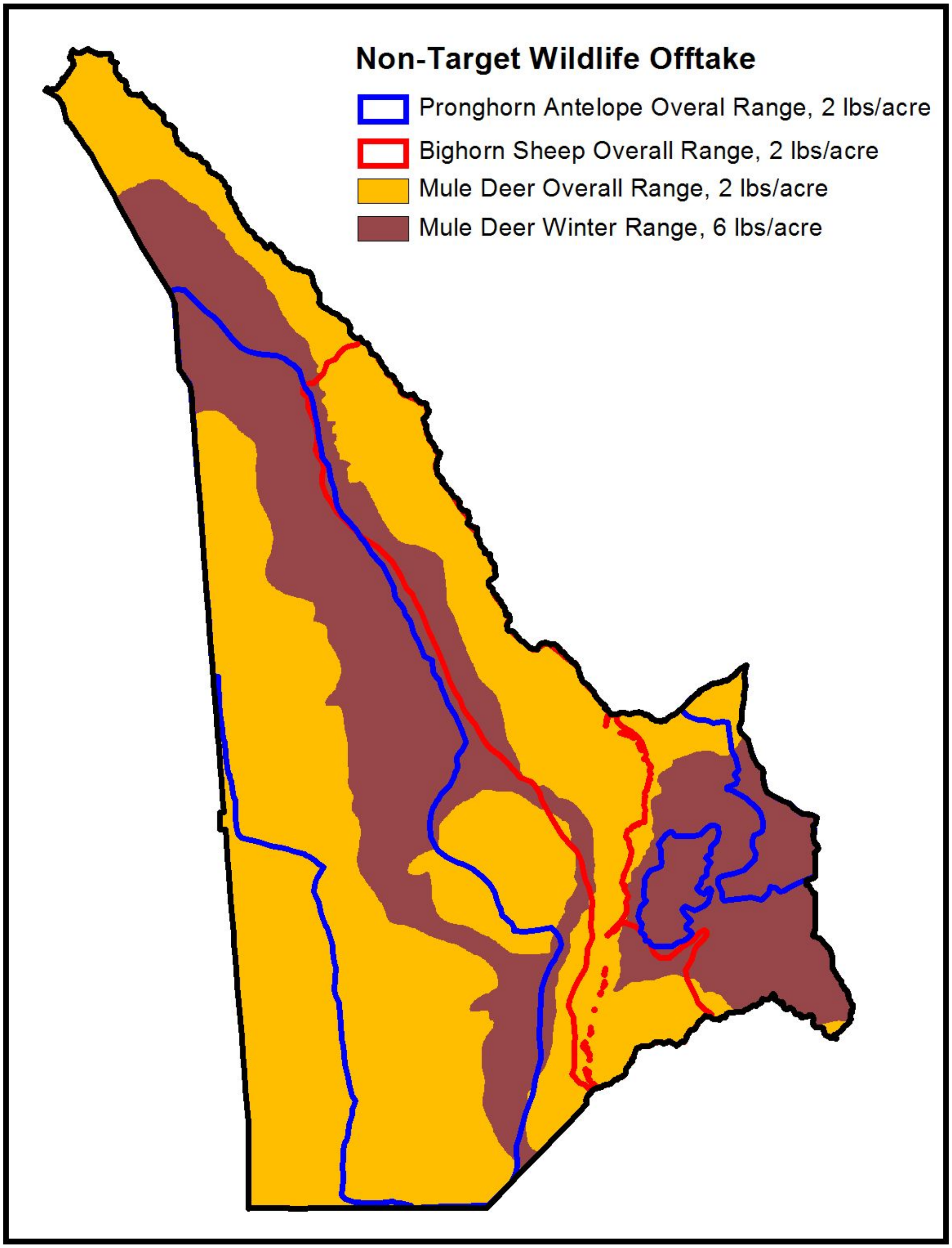

Figure 5. Non-target wildlife offtake.

E. Bison Range and Offtake

In the Great Sand Dunes ecosystem, bison are grazed on The Nature Conservancy's Medano Ranch property. The current range of bison within the fenced area is 32,306 acres. The population size of the bison has varied over the past few years, with the current population being around 2,000 animals. Park managers are interested in predicting elk carrying capacity using bison herd sizes of 0 animals, 1,000 animals, and 2,000 animals. To create these varied offtake maps, a very similar methodology was used as in section D above, where the average bison weighs 1,250 pounds and consumes 2% of its average weight per day. The calculations for offtake on the bison range for the three scenarios are:

1. 2,000 bison x 0.02(%)/day x 1,250 lbs x 365 days / 32306 acres = **565** lbs/acre/yr offtake

2. 1,000 bison x 0.02(%)/day x 1,250 lbs x 365 days / 32306 acres = **283** lbs/acre/yr offtake

3. 0 bison = **0** lbs/acre/yr offtake

Figure 6 below depicts the current range of the bison inside of the bison fence – this range was calculated using animal location data gathered by USGS researchers over a 3-year period.

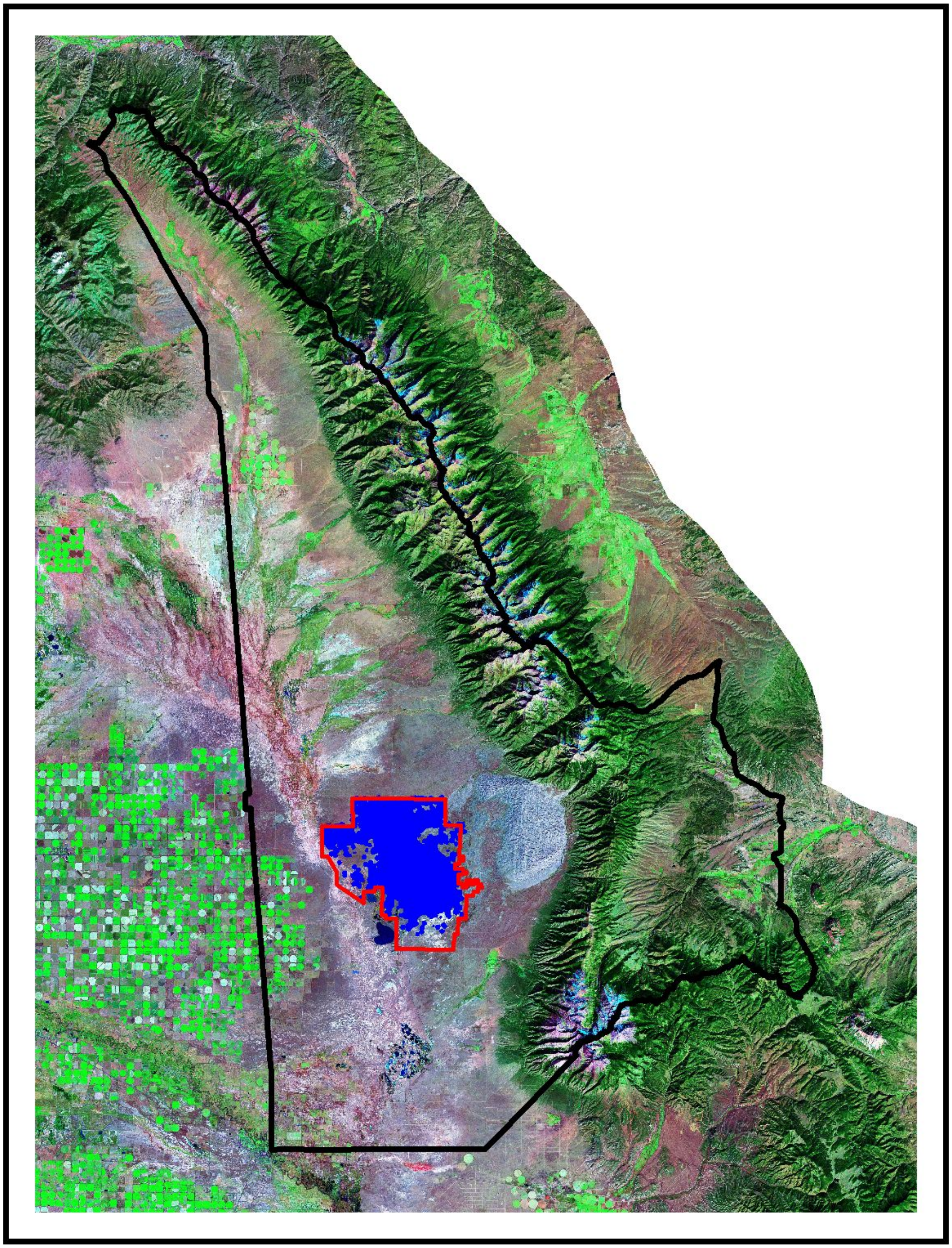

Figure 6. The bison are fenced inside of the red outline, while the blue areas represent their current range based on 3 years of radio collar data.

F. Livestock Offtake

Similar to bison and non-target wildlife livestock utilize some of the same areas for forage. Trying to accurately determine livestock offtake can be a difficult task since many ranching operations use both private and public lands at varying intensities throughout the year.

We created a livestock offtake map throughout the study area (Figure 7). We sought to distribute livestock offtake throughout Colorado Division of Wildlife's GMUs 82 and 861. To do so, we needed some spatial data to serve as the base, by which offtake would be assigned. Given that livestock management differs by land owner or management group, we used a recent and detailed ownership map for Colorado (COMaP; Theobald et al. 2008). The area included lands owned or managed (hereafter for brevity, 'managed') by 13 groups (Table 2).

In the map, private lands are grouped into a single category. We therefore used livestock ownership numbers from the 2007 Census of Agriculture specific to each county, to reflect stocking on private lands. To estimate how many of the reported animals occurring in each county may occur in the study area, we merged a statewide database of forage production estimates (USDA NRCS STATSGO data) with a map of irrigated pasture lands identified in the CVM8 vegetation map (Theobald et al. 2004). We assigned production estimates of 3,000 lbs/ac/yr to irrigated pastures. We then calculated how much of the total forage production on lands of all ownership in each county was within the study area (i.e., Alamosa – 38.1%; Huerfano – 13.5%; Saguache County – 23.7%). These values were used to estimate the number of cattle and sheep in each county that occurred within the study area. For example, Census of Agriculture statistics from 1992, 1997, 2002, and 2007 show long-term livestock populations in Alamosa County as 12,900 cattle, 1,997 sheep, and 1,066 horses. We therefore represented offtake in the private lands of Alamosa County included in our study area 4916 cattle (12,900 * 0.381), 761 sheep (1,997 * 0.381), and 406 horses (1,066 * 0.381). This gave us a general stocking rate for lands within each county, based on governmental statistics. We applied these values to the numerous parcels of private land in the area, and sought more refined estimates for the large blocks of public land.

Information for other land managers varied (Table 2). The Colorado Division of Wildlife and Manitou Institute own small parcels in the study area, and stocking on those parcels was assumed to be zero. Personnel within the State Land Board provided stocking rates for sections of their lands within our study area, classing them as 'better', 'average', or 'poor.' Stocking ranged from 4-5 ac/AU to 8-10 ac/AU. Colorado State Parks confirmed that their lands are not grazed by livestock. The Orient Land Trust informed us that the western portion of their parcel is a ranch managed at typical stocking rates, and the eastern portion is not grazed. The San Isabel Land Protection Trust leases 40-80 ac of land for grazing, the remainder is not grazed; a very low offtake was assigned. We have been unable to locate information on stocking rates in lands managed by The Nature Conservancy. A default modest offtake of 73 lbs/ac/yr was used for those lands, following calculations on stocking rates in Bureau of Land Management allotments.

The US National Park Service provided us with detailed estimates of stocking in their lands, which are mostly not grazed by livestock (here, as elsewhere in this report, bison are not combined with livestock). Members of the Bureau of Land Management in Saguache and Alamosa Counties provided us with detailed grazing leases on allotments. Stocking on allotments within Huerfano County (GMU 861) are not yet available. We assigned a default offtake of 73 lbs/ac/yr to those lands, based on typical offtake of other Bureau of Land Management allotments. The US Fish and Wildlife Service provided detailed historical and current grazing and stocking patterns on their lands. Lastly, the US Forest Service confirmed that most of their lands are not currently grazed, with one active allotment.

After assigning offtake values to each of the land ownership parcels, we used the forage production map described in a previous section of this report to calculate its average forage production. We then calculated the deviation from the average for each cell (equal to each acre) in the raster map. This yielded a surface with values across the map spanning from 1,644 lbs below the mean to 1,987 lbs above the mean. The surface was then divided by 1,987, yielding a normalized deviation map with values between -1 and 1 (in practice, from -0.827 and 1.0).

Using the normalized deviation map, we explored multipliers to that map, where deviations were assigned to livestock offtake assigned to parcels. Objective methods of defining this multiplier would require highly detailed offtake estimates that are unavailable to us, so we subjectively identified a multiplier of 50 as yielding a reasonable distribution of livestock offtake across the landscape. The offtake within each of the ownership parcels remained in agreement with the offtake that followed from the stocking identified by the land managers. The map resulting from applying these methods may overestimate stocking somewhat, given that some animals grazed on private lands and reported in the Census of Agriculture may also graze on lands managed by one of the other entities. But in turn, it may underestimate stocking somewhat, given that areas shown as zero grazing (e.g., most Forest Service lands) may be grazed by livestock occasionally. The final livestock offtake map appears in Figure 7.

Table 2. Owners in the study area, and general offtake information provided.

	Land Owner or Manager	Acres[a]	Offtake data[b]
1	Private	297,565	County-level
2	Colorado Division of Wildlife	14	Small, not pursued
3	Colorado State Land Board	74,870	By quadrant
4	Colorado State Parks	323	Detailed
5	Manitou Institute / Crestone Baca Land Trust	107	Small, not pursued
6	Orient Land Trust	1353	Detailed
7	San Isabel Land Protection Trust	466	Detailed
8	The Nature Conservancy	51,954	Few data provided
9	US National Park Service	113,519	Detailed
10	US Bureau of Land Management	87,780	Detailed, except GMU 861

11	US Fish and Wildlife Service	58,177	Detailed
12	US Forest Service – Pike	30,717	Detailed
13	US Forest Service – Rio Grand	113,275	Detailed

a – Some rounding occurred in the original source and during our spatial analyses.

b – For specifics about the offtake data available, see the text.

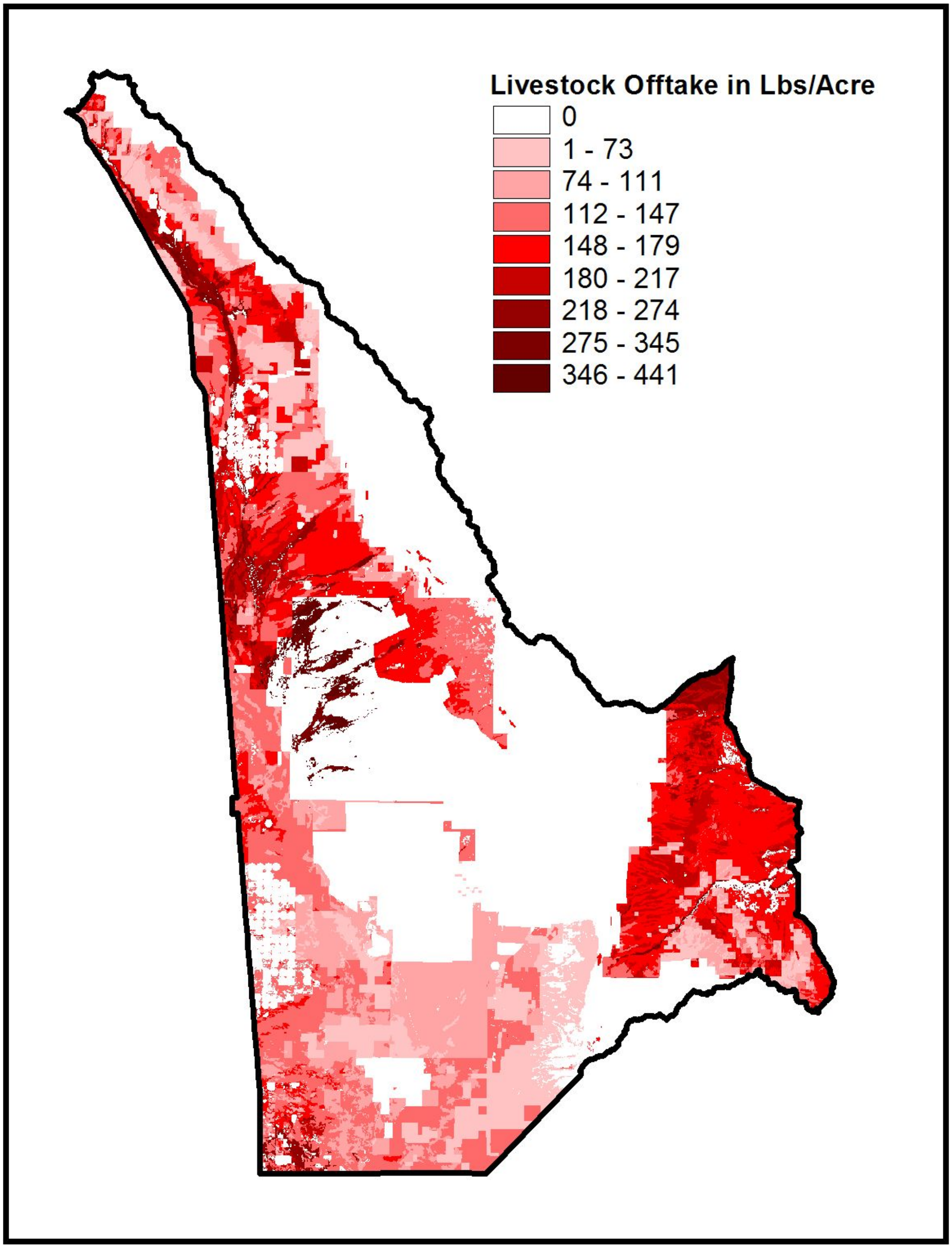

Figure 7. Livestock offtake in pounds/acre for the study area.

IV. ECCM Methodology

The ECCM is designed to be a simple, transparent tool to facilitate the implementation of sound habitat management practices. Wildlife population management decisions have typically been based on population models. These population models often incorporate minimal information regarding the feedbacks that exist between herbivory and vegetation or resource availability (Weisberg et al. 2002). The ECCM uses simple forage accounting theory, and all calculations rely on straightforward arithmetic.

The ECCM uses GIS raster-based layers called grids and vector-based layers called polygons to achieve the calculations. Each subtraction involves a "grid subtracted from a grid" while summing involves simple calculations of adding up all the forage shown in a grid that falls within a designated polygon. The logic is easy to follow, and can be visually portrayed using the grid and polygon GIS layers. The logic used in the model methodology is as follows:

1. Start with Vegetation Production (annual net primary productivity, or ANPP) on the entire study area.

2. Calculate "Habitat Sustainability Threshold" – the amount of vegetation production that must not be grazed.

3. Subtract livestock offtake.

4. Subtract offtake from bison.

5. Subtract offtake from other wild ungulates – mule deer, pronghorn, and bighorn sheep.

6. Sum how much vegetation remains inside of the elk range.

7. Using the thresholds defined in #2, calculate how many elk can be fed for the entire year (12 months) with the amount of leftover vegetation in #6, where elk are assumed to have an average weight of 500 lbs. This represents the "carrying capacity for elk" at the low, mid-point, and high threshold levels discussed earlier in this report.

V. ECCM RESULTS AND SCENARIOS

Scenario A: Baseline

We created a "baseline" result scenario for the study area using the following assumptions:

1. Mean precipitation – although models can create results based on varying precipitation levels, wildlife managers cannot manage wildlife based on yearly fluctuations of rainfall. Therefore the baseline results, and all scenarios (except for the "climate change" scenario) use mean precipitation as the source for the vegetation production map.
2. Livestock offtake in a mean precipitation year – although livestock numbers can vary dramatically by forage availability, the baseline model and all scenarios use only one livestock offtake map based on mean precipitation and thus mean stocking levels.
3. Unvaried numbers of mule deer, pronghorn antelope, and bighorn sheep – these species abundances are never varied in any modeling scenario.
4. 2,000 bison – the current number of bison in the study area is approximately 2,000. This will be varied in forthcoming scenarios.
5. Normal irrigation and haying on the Baca National Wildlife Refuge – this will be varied in a forthcoming scenario.

Baseline Results Table

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
3,790	6,104	8,417

Discussion: Based on mean precipitation, mean livestock, other wildlife numbers that reflect current counts on the landscape, 2,000 bison, and normal irrigation/haying operations on the Baca, the model suggests that the carrying capacity for elk in the areas they use within GMUs 82 and 861 (within the polygons in Figure 4) is 6,104, with a low threshold of 3,790 and a high threshold of 8,417.

The current population for elk on the study area is approximately 5,000 individuals (Lubow and Schoenecker, in review; B. Weinmeister, Presentation to CO-TWS, Aug. 2009). Thus, the model suggests that the landscape is currently being grazed by elk between the low threshold and mid-point for carrying capacity. Because the grazing intensity is lower than the mid-point on the entire landscape, the habitat is likely being protected and elk numbers are likely not maximized across the entire landscape.

Consequently, if there are human-elk conflicts on the study area, these conflicts are likely due to the “distribution” of elk across the landscape, rather than an “overabundance” of elk across the landscape. To address these conflicts, we suggest using management options that re-distribute elk or protect sensitive vegetation rather than reducing the overall numbers of elk across the landscape.

Scenario B: Varied Bison Numbers

For this scenario, all other variables in scenario A were held constant, other than bison numbers.

Results With 1,000 Bison

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
6,181	8,494	10,808

Results With Zero Bison

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
8,580	10,984	13,207

Discussion: With 1,000 or with zero bison on the present bison range, significantly more elk can adequately find forage to survive on the landscape. If resource managers decide to reduce the size of, or eliminate, the bison herd, elk numbers can grow to 8,494 (with 1,000 bison) or 10,984 (with zero bison) and still meet habitat carrying capacity limitations for the entire landscape.

Scenario C: No Irrigation or Haying on the Baca National Wildlife Refuge

The Baca National Wildlife Refuge comprises about 58,000 acres, part of which is irrigated, hayed, and grazed. At the request of Park and Refuge managers, we created a scenario to mimic less habitat manipulation on the Baca National Wildlife Refuge. For this scenario, all other variables in “Scenario A” above were held constant, except for the initial vegetation map. In the initial vegetation map used in Scenario A above, the average production across the Baca was 758 pounds/acre. This production value includes the effect of irrigating and then haying selected areas on the Baca, which also includes a value of 750 pounds/acre on “leftover stubble” after haying. For Scenario C, we assumed that no irrigating or haying occurred, and thus we turned the average production values across the Baca to a “native vegetation” level that mirrored the average across the landscape surrounding the Baca. This “native vegetation” level was 600 pounds/acre.

Results *Without* Irrigation and Haying on the Baca NWR but *With* Livestock

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
3,192	5,416	7,640

Results *Without* Irrigation and Haying on the Baca NWR *Without* Livestock

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
4,373	6,597	8,821

Discussion: If irrigating and haying no longer occur, the elk carrying capacity will decrease from 6,104 animals to 5,416 animals (mid-points) as compared to baseline. This decrease occurs because the average production value for "native vegetation" on the Baca (600 lbs/acre) is lower than the average production value accrued after irrigating and haying (758 lbs/acre). If livestock are also removed from the property, then elk carrying capacity will increase from 6,104 animals to 6,597 animals. Management activities on the Baca can make an overall +/- 10% impact on the total carrying capacity for the entire study area.

Scenario D: Climate Change

Climate change introduces considerable uncertainty on western landscapes. Cumulative long-term impacts are very difficult to ascertain. Some global circulation models predict more annual precipitation by 2050, and some predict less. In general, however, the models agree that temperatures will increase, and that seasonal patterns of precipitation will change. Many scientific studies suggest that summer precipitation will decrease as temperatures increase in western Colorado (Ray et al. 2008). Less precipitation in the summer suggests that forage production will decline. The future under climate change is extremely difficult to predict (e.g., C_3 plant production may increase because of increased CO_2 concentrations), but we wanted to provide some indication of changes in the capacity of the system to support elk if forage production declines under reduced precipitation.

Scenario D offers a very simplistic estimate of the potential impact a climate change could have on the elk carrying capacity in the study area. For this scenario, overall vegetation production is reduced by 10%, accounting for less rainfall during the growing season in the study area.

Results For a Climate Change Scenario that Results in 10% Less Forage Production

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
2,191	4,273	6,356

Discussion: If climate change results in 10% less forage production on the landscape, elk carrying capacity will be reduced from 6,104 animals to 4,273 animals (mid-point). Other types of changes may also occur that are difficult to estimate, including changes in vegetation composition which could shift elk distribution and/or migration patterns.

Scenario E: Federal Clip-Out

Park managers requested an evaluation of the federal complex of lands, so we present two "clip-out" scenarios. The scenarios hold every variable constant as presented in the baseline Scenario A above. The first scenario calculates the elk carrying capacity only within the federal and TNC landscape: the Great Sand Dunes Park and Preserve, the Medano Ranch, and the Baca National Wildlife Refuge. The second scenario removes bison from the Medano Ranch. The locations of the areas are depicted in Figure 8.

Results for Great Sand Dunes Park and Preserve, Medano Ranch, and Baca National Wildlife Refuge

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
971	2,038	3,104

Results for Great Sand Dunes Park and Preserve, Medano Ranch, and Baca National Wildlife Refuge Without Bison

Estimated Carrying Capacity For Elk		
Elk Low Threshold	Elk Mid-point	Elk High Threshold
5,743	6,810	7,876

Discussion: While the entire study area can support 6,104 elk, the Park and Preserve, Refuge, and Medano Ranch, can support about 50% of that. Removing bison from the Medano also increases forage available to elk and thus increases carrying capacity. Because elk migrate all over the study area, it would be impossible to manage elk just on these federal parcels. However, by clipping out and estimating the carrying capacity for this section, managers can see the component that federal property offers to the whole study area's carrying capacity.

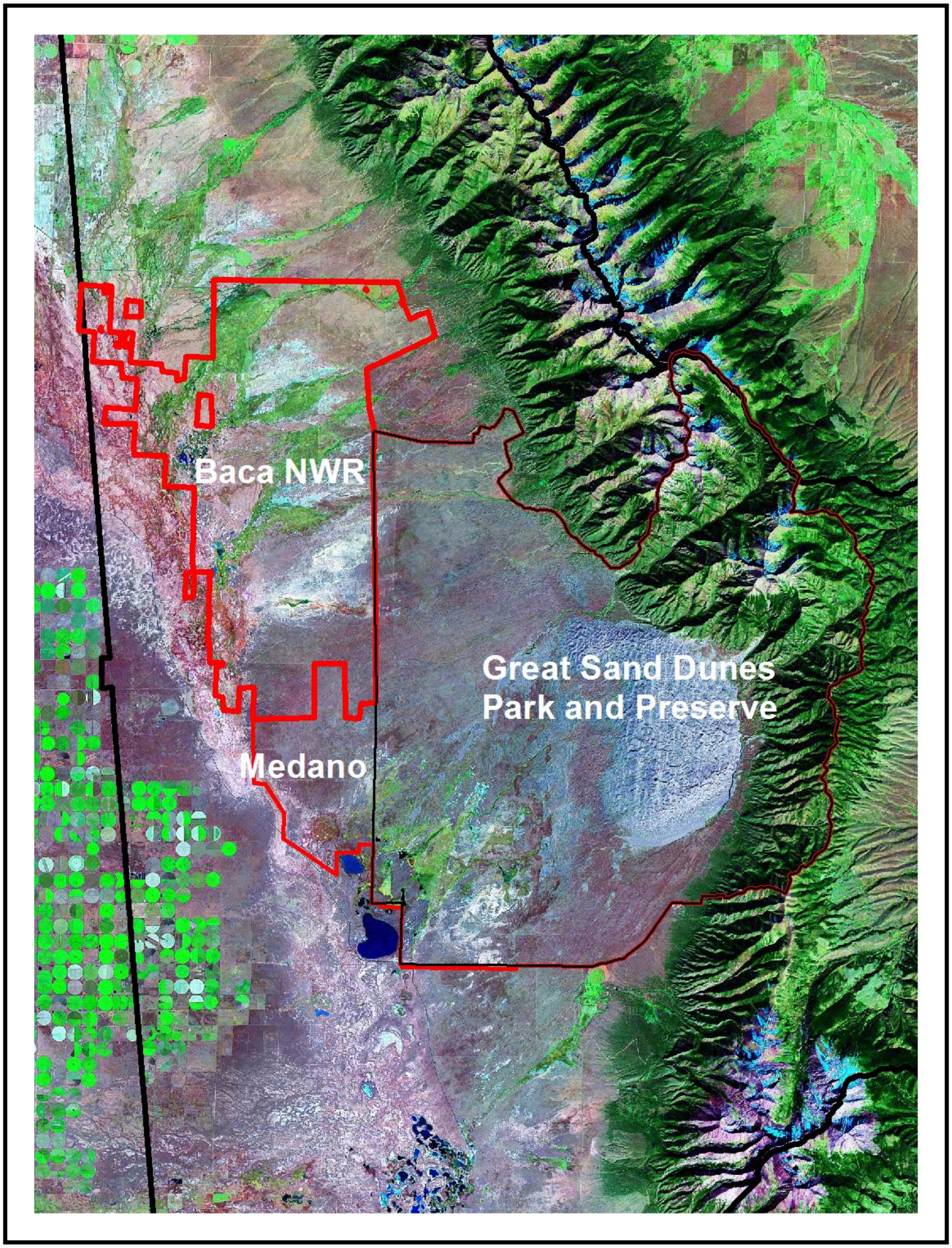

Figure 8. Federal and conservation land boundaries for Scenario E.

PART TWO: BISON CARRYING CAPACITY MODEL (BCCM)

I. Introduction

Managers in the Great Sand Dunes ecosystem are interested in bison carrying capacity as well as elk carrying capacity. Bison currently graze on the Medano Ranch. Although they are free-roaming on the Ranch, it is fenced and annual roundup and removals keep the herd at pre-determined levels. In 2009 at the time of this modeling exercise, the bison herd was approximately 2,000 animals.

Determining the appropriate number of bison on the ranch is a task that is best done with a comprehensive, fine-scaled dataset for the Ranch including vegetation type, vegetation production, and sustainable offtake estimates that captures the spatial heterogeneity of the area. This BCCM utilizes the same large-scale, landscape level dataset as used in the ECCM. Thus, this BCCM should be considered a broad-ranging model that creates gross estimates.

Because of these data limitations, the bison carrying capacity estimate we employ provides a broad range of numbers for managers to consider, rather than a narrower band of estimates as generated in the ECCM.

II. Habitat Sustainability

The BCCM is designed to calculate the carrying capacity for bison on the Medano Ranch given the goal of ensuring that the habitat remains sustainable for the long-term health of the vegetation and for grazing ungulates. The BCCM promotes habitat sustainability by not allowing a portion of the vegetation production to be consumed by ungulates. Please refer to Part One, Section II of this report for more explanation of the concept of "habitat sustainability."

The BCCM differs from the ECCM in one significant way: while the ECCM calculates carrying capacity based on habitat sustainability measurements from the entire landscape – a landscape that varies from 7,000 feet of elevation to 13,000 feet – the BCCM focuses only on a valley floor section of this landscape. This valley floor contains a higher percentage of vegetation types that contain palatable grasses, such as wet meadows, and mesic meadows. Thus, a higher "sustainability factor" is offered as the "midpoint" and "high threshold" in the BCCM. Stated differently, the BCCM allows more of the vegetation to be eaten by grazing ungulates to account for the higher productivity in vegetation types found on the Ranch.

In the ECCM, we allowed between 25% and 32% of the vegetation production to be grazed, in the BCCM we allow between 25% and 75%. Obviously this is a wide range of values that produces a wide range of results, but there is some justification for using these wider values. Vegetation sampling on the Ranch completed by USGS and NPS (Zeigenfuss and Schoenecker, unpublished data) showed that average annual wildlife offtake (for bison, elk, deer, and pronghorn) on herbaceous understory plants in cottonwood dominated areas was 70.5%, in wet meadows was 64.5%,in willow dominated areas was 72%, and in mesic meadows was 79%. These high offtake levels may or may not be sustainable on these specific vegetation types – and are likely not sustainable on surrounding non-mesic vegetation types – but we thought it useful to incorporate a range of habitat sustainability measurements that approached those measured on the ground by the scientific crew.

If managers want to refine the habitat sustainability factors on the Ranch, we strongly recommend that more field data be collected, perhaps over a ten-year period, so that longer-term vegetation sustainability can be better estimated.

III. Data Input

Study Area: The Medano Ranch contains roughly 41,000 acres, sitting immediately west of the Great Sand Dunes. The Ranch is a nearly flat landscape, ranging between 6,500 and 7,000 feet of elevation. A map of the Medano Ranch study area is in Figure 9 below.

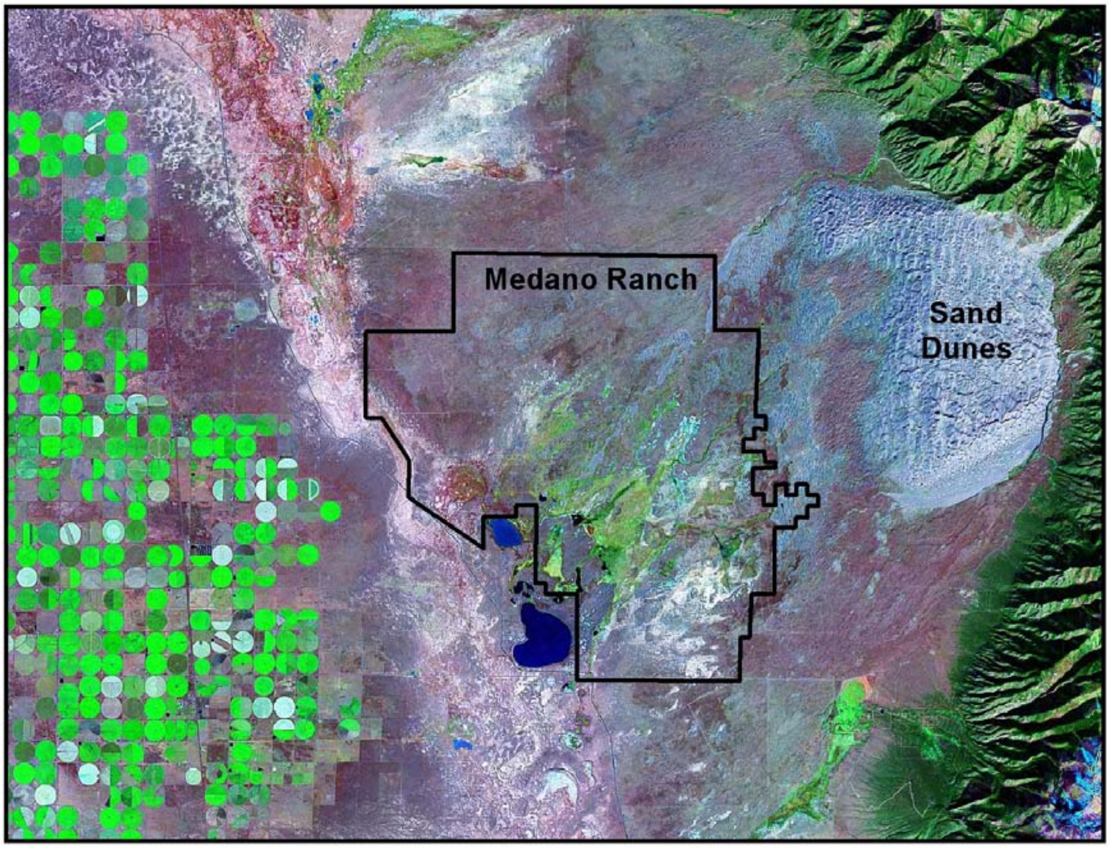

Figure 9. Medano Ranch Study Area

Vegetation Type and Production: Vegetation types and production values are shown in Figure s 2 and 3. The Medano Ranch area was clipped out for the purposes of modeling this specific study area.

Elk Range and Other Wildlife Offtake: The elk range and offtake by other wildlife was calcuated in the same way as the ECCM

Livestock Offtake: There is no cattle or sheep grazing on the Medano Ranch.

Bison Range: While the bison have historically only used about 80% of the Ranch (see Figure 6), the entire Ranch was made available to bison for this modeling exercise. Stated differently, the model estimates carrying capacity for bison based on the vegetation on the entire Ranch, not just on the areas bison used for the past 3 years from empirical data.

IV. Bison Carrying Capacity Methodology

The BCCM is a simple, transparent model. It uses the same GIS grids and polygons as in the ECCM, and uses similar mathematical calculations. The logic used in the model methodology is as follows:

1. Start with Vegetation Production (ANPP) on the Medano Ranch.

2. Calculate “Habitat Sustainability Thresholds” – the amount of vegetation production that must not be grazed (25% - 75%).

3. Subtract offtake from other wild ungulates – mule deer, pronghorn.

4. Subtract elk offtake for varying numbers of elk including 0 elk, 500 elk, 1,000 elk, and 1,500 elk (assume elk are on the Ranch for 12 months/year).

5. Sum the amount of vegetation production remaining inside of the Medano Ranch.

6. Using the thresholds defined in #2 (25% - 75%), calculate how much vegetation production is available to bison and thus how many bison can be fed for the entire year (12 months). A bison is assumed to have an average weight of 1,000 lbs. This represents the “carrying capacity for bison” at the low, mid-point, and high threshold levels discussed earlier in this report.

V. BCCM RESULTS

The following result table assumes mean precipitation and unvaried mule deer and pronghorn offtake.

Bison Carrying Capacity on the Medano Ranch

	Low Threshold 25% offtake	**Mid-point 50% offtake**	**High Threshold 75% offtake**
With 0 elk (12 months on Ranch)	**751**	**1,570**	**2,389**
With 500 elk (12 months on Ranch)	**438**	**1,256**	**2,075**
With 1,000 elk (12 months on Ranch)	**246**	**1,065**	**1,884**
With 1,500 elk (12 months on Ranch)	**55**	**874**	**1,693**

Discussion:
As stated earlier, given that the Ranch is a low-elevation valley floor, and that vegetation types are more palatable for ungulates, we used a wide range for calculating thresholds. It is questionable whether the 50% or 75% offtake levels are sustainable year after year, but empirical data suggests it is occurring currently.

Given the datasets available to us, we suggest that the habitat sustainability on the Ranch would be better achieved nearer to the midpoint (50% offtake level) than at the high threshold. Thus, bison numbers between 874 and 1,570 likely represent the range of carrying capacity for the Ranch under varying elk numbers.

We again suggest that further fieldwork should be done to measure vegetation production on the Ranch and to estimate sustainable grazing levels on that vegetation in order to refine the BCCM.

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