Assessing Management Alternatives for Ungulates in the Greater Teton Ecosystem using Simulation Modeling

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Final Report

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Introduction

Managers of ungulate populations in the Greater Teton Ecosystem and the National Elk Refuge have asked three questions about interactions between populations of native ungulates, notably elk and bison, and the winter habitats that support those populations. We addressed these questions using simulation modeling.

The first question focuses on understanding the balance between supplies of forage on the winter range and the size of ungulate populations. In short, managers seek to know the number animals that can be supported by natural forage supplies under a range of weather conditions. To answer this question, we created the Forage Accounting Model (Part I of this report). The Forage Accounting Model simulates forage intake by ungulates across a range of elk population sizes and during a range of climatic conditions for the growing season and for winter. In addition, we simulated varied bison populations between 250 and 2000 animals for the Teton ecosystem. This model predicts the proportion of forage supplies that are consumed across the landscape (forage utilization) and also calculates 'forage deficits' caused by different population sizes in the system. Forage deficits represent the difference between the total supply of forage and the total forage required by ungulates. We exercised the Forage Accounting Model using assumptions from four of the Alternatives in the ongoing Environmental Impact Statement for ungulate management.

The forage accounting model predicts forage utilization by ungulates, but does not provide insight into the consequences of different levels of utilization. Thus, the second question we addressed focuses on the impacts of different levels of utilization of winter forage on ecosystem processes, primarily net primary production and nutrient cycling. To answer this question, we used the CENTURY Ecosystem Model (Part II of this report). The Century model simulates biogeochemical changes in vegetation and soil due to grazing. Using this model, we simulated intense grazing effects on two vegetation types prevalent on the Teton winter range -- wet meadow and sagebrush. We examined the effects of two levels of utilization (50% and 80%) on soil carbon, mineralized nitrogen, and net annual production over a one-hundred-fifty year time-span. Ongoing fieldwork by F. Singer will later be used to corroborate these simulations.

The third question focuses on the consequences of forage deficits for population performance. Specifically, we asked "What are the effects of food shortages on elk mortality? To answer this question, we employ the Over-Winter Mortality Model (Part III of this report). The Over-Winter Mortality Model estimates the energy balance of individual elk and simulates energy intake and expenditure in four age/sex classes. We estimate starvation mortality using the same scenarios for animal abundance, available forage, and snow conditions as in the Forage Accounting Model.

These three models complement each other in important ways. The Forage Accounting Model predicts forage supply, consumption, deficits, and utilization. The Century Ecosystem Model was developed for different projects at the Natural Resource Ecology Lab at Colorado State University and then adapted to our present needs, in part by using the utilizations predicted by the Forage Accounting Model. The Over-Winter Mortality Model was first developed for mule deer in Colorado and was adapted for elk to meet the needs of this project. It uses the forage supply, consumption, and deficits predicted by the Forage Accounting Model. We brought these three models together to provide reasonable answers to the questions raised by managers.

Here, we describe each model and the insight we gained from it. The first three sections of this document focus on each model and its results. In a final, concluding section, we aggregate results across models and draw general conclusions relevant to managing ungulates in the Greater Teton Ecosystem.

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Executive Summary

The Forage Accounting Model
We describe a simple accounting model that predicts imbalances between forage supply and animal forage requirements on winter ranges used by native ungulates (elk, moose, bison) in the Greater Teton Ecosystem and the National Elk Refuge. The model predicts *forage utilization* and *forage deficits.* Forage utilization is depicted by a map across the study area where cells are coded based on the percentage of pre-winter forage supplies that are consumed by native ungulates during winter. Forage deficits are defined as the amount of forage required by ungulates that exceeds the amount available during any week of the winter, summed over all weeks. The model is driven by data on forage standing crops at the beginning of winter, snow distribution during winter, pre-winter precipitation conditions, and offtake rates of ungulate populations.

We exercised the Forage Accounting Model in the Greater Teton Ecosystem under different conditions for elk population density (0-18,000 animals), and under different bison populations (250 - 2000) while holding moose populations constant (890). In addition to simulations for the ecosystem as a whole, we also exercised the model solely on the National Elk Refuge with elk populations of 0 -10,000, bison populations of 250 -2000, and 20 moose. The number of elk at which forage deficits begin to occur during a specific winter under specified assumptions represents an "equilibrium point" on the landscape at which forage supply and demand are in balance. Table 1 below provides a quick synthesis of these equilibrium points for each scenario in the EIS process for the broader Teton study area and NER.

Table 1. Number of elk at which forage supply and demand are in equilibrium

Alternative #1 (status quo, 500 bison, flood irrigation, willow available on NER)						
Pre-winter Precipitation Scenario	Drought			Mean		
Snow Severity Type	Severe	Above-average	Average	Severe	Above-average	Average
Greater Teton Ecosystem	0	1,800	5,500	1,000	6,000	16,000
NER only	0	0	2,000	0	0	5,000
Alternative #2 (no flood-irrigation, 500 bison, willow available on NER)						
Greater Teton Ecosystem	0	1,600	5,300	900	5,900	15,800
NER only	0	0	1,700	0	0	4,500
Alternative #3 (no willow available on NER, 1,000 bison, flood-irrigation)						
Greater Teton Ecosystem	0	0	3,000	0	5,000	14,000
NER only	0	0	0	0	0	3,300
Alternative #4 (center-pivot irrigation, 350 bison, no willow available on NER)						
Greater Teton Ecosystem	0	1,600	5,700	1,500	7,200	17,000
NER only	0	0	2,000	0	0	5,500

Although the numbers in Table 1 represent clearly demarcated points of equilibrium, each is associated with a margin of error, underlying assumptions, and an accompanying graph in the body of this report which should all be evaluated together. Additionally, although the numbers of elk in Table 1 represent the point at which deficits begin to occur, elk are known to rely on stored energy reserves to survive winters and therefore can likely incur small forage deficits without starving to death.

In addition to the above analysis, we also ran experiments with the Forage Accounting Model on the Greater Teton Ecosystem to examine effects of 1) removing all domestic grazing from public lands in the Teton ecosystem and 2) removing effects of agriculture and residential development on forage supplies in and around the town of Jackson. Our simulations suggested that removing all domestic grazing would have effects on forage deficits in all winter severity types because most domestic grazing does not occur on wildlife winter range. Providing forage to elk populations equivalent to the pre-settlement vegetation now subsumed by development in and around Jackson had negligible effects on forage deficits during severe winters. During average winters adding this forage substantially reduced deficits. by allowing elk to graze on the additional forage available. However, addition of these forage supplies did not *eliminate* forage deficits for the current population size of elk, suggesting that current elk numbers may exceed what could have been support in the Greater Teton Ecosystem under pristine conditions.

The CENTURY Ecosystem Model

The CENTURY Ecosystem Model simulates exchanges of carbon (C) and nitrogen (N) among atmosphere, soil, and vegetation. Required inputs used to drive the model include monthly maximum/minimum temperature and precipitation data, soil properties, vegetation type, and current and historical land use. Disturbances and management practices such as grazing, fire, cultivation, and fertilizer additions can be simulated. We simulated response of two vegetation types (wet meadow and sagebrush) to two levels of forage utilization by elk (50% and 80%)/ Other required inputs were estimated based on CENTURY modeling in similar systems. Current and ongoing Teton field sampling work by F. Singer on nitrogen pools and vegetation will later be used to corroborate these preliminary findings.

Because elk are consuming standing dead forage of low nutritional content during winter, CENTURY predicted that ungulate grazing will have not harm plant production on the winter range at either level of grazing intensity. Further, because grazing accelerated nutrient cycling, and because ungulates returning more nitrogen to the soil than they consume, higher grazing levels may actually *increase* future plant production. Resutls from CENTURY suggest that heavy winter-season grazing in this system, as predicted by the Forage Accounting Model, is sustainable and that soil C and nutrient levels are not significantly depleted and may increase. As long as elk are concentrated at high densities on the winter range, the CENTURY model will predict positive feedbacks on production due to higher net N inputs versus N offtake from grazing.

The Over-Winter Mortality Model

Forage deficits predicted by the Forage Accounting Model will likely cause elevated mortality in over-wintering elk populations. We adapted the energy balance model of Hobbs (1989) to estimate starvation mortality by simulating energy intake and expenditure by elk in four age/sex classes (calves, yearling males, adult females, bulls) during average, above average and severe winters with average pre-winter precipitation conditions. This energy balance model allocates elk populations to map cells based on snow water equivalents, allows elk to consume available herbaceous and shrubby forage, and predicts mortality based on forage shortfalls and animal nutritional needs.

Simulated mortality of calves ranged from a low of 4% during an average winter at a total population size of 6,000 to a high of 42% during a severe winter and a population of 18,000. Increasing population density was associated with roughly proportionate increases in estimated mortality. Starvation mortality for adult cows was predicted to be 1% for a population of 6,000 animals in an average winter rising to a high of 25% for a population of 18,000 during a severe winter.

Acknowledgements

Funding was provided by the Natural Resources Preservation Program (NRPP) – US Geological Survey, BRD and NPS fund, and from Grand Teton National Park. We acknowledge Robert Schiller of Grand Teton National Park for project organization and administration as well as Bruce Smith of the National Elk Refuge. We also thank Phil Farnes of Snowcap Hydrology and Montana State University for the snow model algorithms and snow measurements, and for assistance with refining the snow model; and Michael Coughenour of the Natural Resource Ecology Lab (CSU) for developing the snow model computer code.

Part I.
The Forage Accounting Model

Introduction

We constructed a forage accounting model to examine the consequences of management actions for balancing forage supplies with forage demands of populations of native ungulates in the Greater Teton Ecosystem and the National Elk Refuge. We first describe our modeling approach and explain two predictions made by the model, forage utilization and forage deficits. We then describe how the model works. We subsequently use the model to examine relationships among elk population density, bison populations, precipitation-based forage production, and winter severity. The model was run on two study areas: the Greater Teton Ecosystem, and the National Elk Refuge, and was used to predict forage deficits for each Alternative in the EIS on both study areas. In addition to describing the modeling approach and methods, this section of this report gives and interprets the results for all four EIS Alternatives.

Modeling Approach

Our modeling philosophy favors simple models over complex ones. This is because simple models are easier to explain, understand, and defend than models that include high levels of detail. Our approach is to begin with a simple, “base model”, and add detail incrementally as it is needed to address questions unresolved by the simpler model.

We built a simple accounting model that keeps track of the impacts of different densities of ungulates on forage supplies as winter progresses. The model responds to annual variation in forage production, effects of snow on forage availability, and effects of grazing and browsing on the forage supply. We call it an accounting model because it is perfectly analogous to a model of cash reserves and flows in a business. In essence, it answers questions on the bottom line -- how much forage is used by populations of ungulates? Does that use produce a deficit or surplus at the end of winter? The accounting approach was motivated by the overriding central assumption used to justify supplemental feeding -- animals are fed during winter to compensate for deficits in forage supply. Thus, a logical starting point for our efforts was to quantify the magnitude of these deficits under different conditions.

The Concept of Forage Deficits and Forage Utilization

There are two concepts that are important in understanding the accounting model. The first concept is *forage deficits*. Forage deficits represent the difference between the total supply of forage available during the winter and the total forage required by a given population of ungulates, including bison, moose, and elk. Thus, forage deficits are affected by population size, which affects forage demand, as well as snow accumulation (measured as snow water equivalents, SWE) and forage production, which affects forage supply. We calculated forage deficits by estimating the daily intake of populations of a given size, subtracting that intake from the daily forage supply, and summing negative values over all time-steps of the winter.

The second concept, a common measure of habitat use, is called *forage utilization.* Forage utilization is simply the percent of forage removed from a given location in the study area. We depict this on a map where map-cells are coded with the utilization percent. Forage utilization gives us a measure of ungulate impact on habitat. Part II of this report, which discusses the

Century Ecosystem Model, will analyze and quantify the effect forage utilization on net primary production and nutrient cycling.

Model Description

Study Areas

Two study areas were delineated (Figure 1). The first, larger area, the Greater Teton Ecosystem, corresponds to the boundary depicted in the Steele et al. (1999) report on Jackson Valley vegetation. The southern boundary reaches to the southern edge of the Town of Jackson, the northern edge is at the north end of Jackson Lake, the western edge is about halfway between the crest of the Tetons and the Idaho Border, the eastern edge runs roughly to Togwotee Pass. This boundary roughly encompasses the current boundary of the Jackson elk herd as defined by Wyoming Game and Fish. In addition, it contains all of the supplemental snow measurement sites reported by Farnes et al. (1999). The second area is the boundary of the National Elk Refuge.

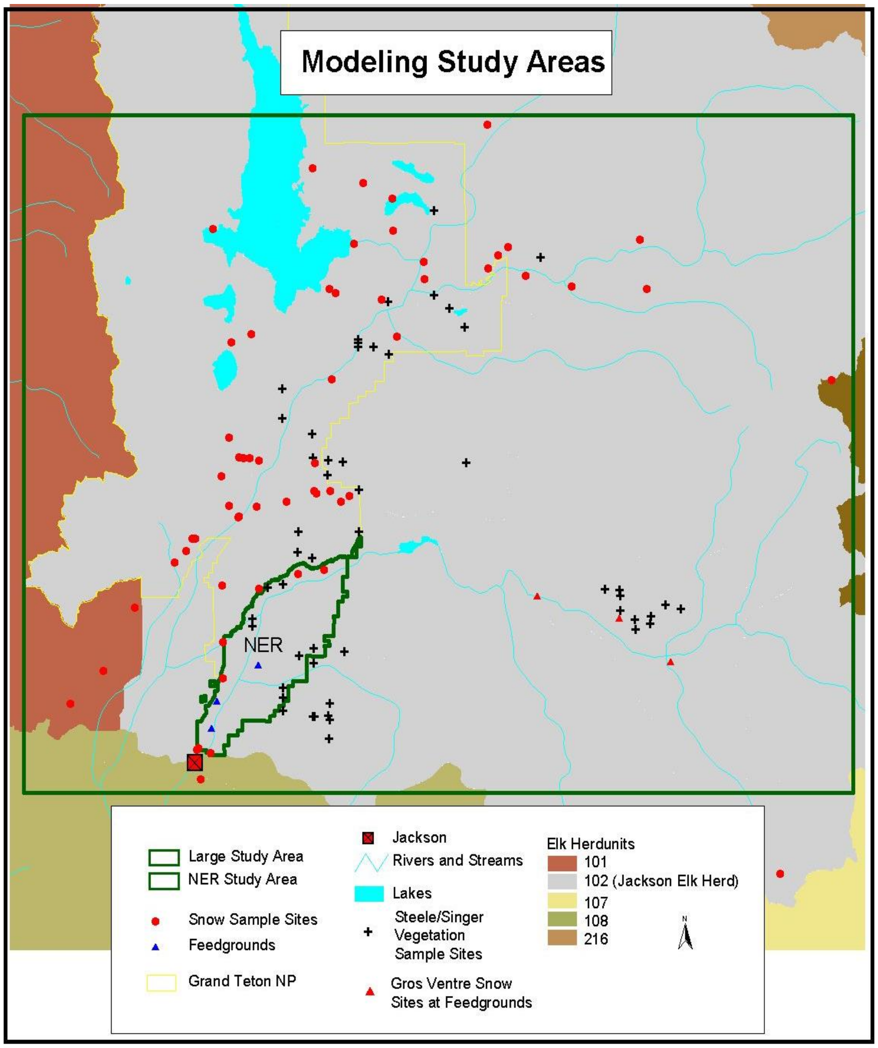

Figure 1. Study areas and other relevant locations for the project.

Algorithm

The model operates at a weekly time step (Figure 2). For each week of the winter, the model calculates snow water equivalents (SWE) on each 30 x 30 meter cell in the study area and sums the amount of forage that is available at each 1-inch SWE increment. Grazing/browsing pressure by populations of bison, elk, and moose is first allocated to the forage available in completely open areas (i.e., cells with 0 inches SWE). If additional demand exists, it is allocated to cells with 1 inch of SWE. Any additional demand is allocated to progressively greater snow depths, with a linear reduction in forage availability occurring in relation to SWE greater than 2 inches (Table 2). This approach has been used successfully to model effects of snow on forage availability in other studies (Hobbs 1989, Turner et al. 1994).

Table 2. Forage Availability Percentages

SWE inches	Percent of forage available
0	100
1	100
2	100
3	75
4	50
5	25
6	0

If there is forage demand in excess of the supply in all of the cells during any week, then this excess is accumulated in the *forage deficit*. At the end of the winter, we calculate *forage utilization* for each cell in the vegetation map by dividing the total amount of forage removed from each cell by the pre-winter standing crop of that cell.

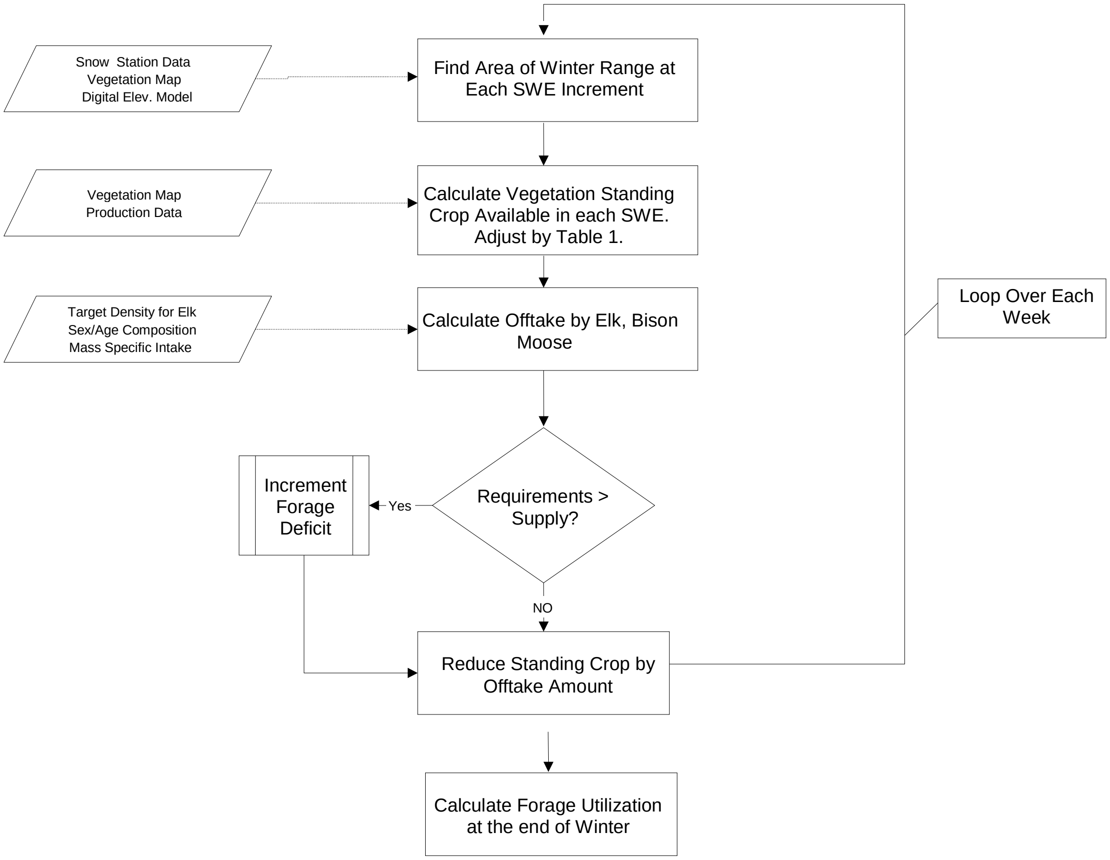

Figure 2. Flow chart of data and processes in the forage accounting model. The model cycles through these calculations at weekly intervals.

The model is driven by data on the standing crop at the beginning of winter, snow distribution during winter, and offtake rates of ungulate populations (Figure 2).

Vegetation Data

The accounting model requires spatially explicit data on production of vegetation available at the beginning of winter. We developed these data from maps of vegetation communities and field data on production in each community.

We obtained a complete vegetation coverage from Utah State University (Homer 1995) that was created in 1996 for all of U.S. Forest Service (USFS) Region 4 using remote sensing interpretation techniques. Vegetation coverages were also obtained from Grand Teton National Park (GTNP) and the National Elk Refuge (NER) (Figure 3). GTNP data were developed from aerial photography while NER data were developed from a combination of aerial photography and ground-based mapping. Discussions with other coverage users suggested that the NER coverage was the most accurate, followed by the GTNP coverage, followed by the Utah State coverage. Thus, we merged these coverages to use the most accurate data wherever it was available, using the Utah State coverage only to fill in gaps not covered by the GTNP or NER data.

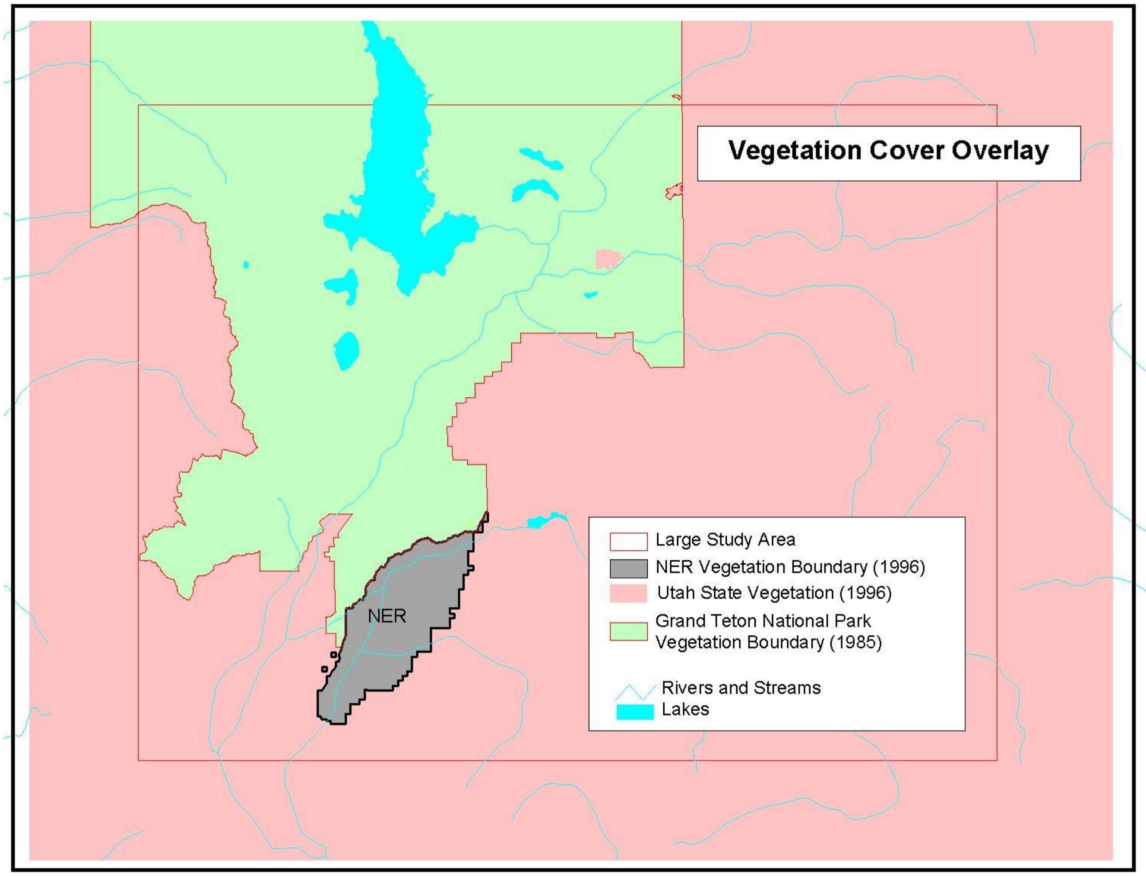

Figure 3. Coverages used to assemble unified vegetation map for the study area.

Because each coverage had different vegetation coding schemes, a crosswalk table was developed to convert the vegetation codes into a more standardized scheme (Appendix C: Table 1). The Utah State coverage had 68 separate vegetation types, GTNP had 60, and NER had 32. The essential data in the vegetation table was the name of the vegetation type and the annual production of herb/shrub. This model folds these categories into 15 separate vegetation types (Figure 4). These categories were chosen because they provided usefully different vegetation types for which we could obtain production information in the nearby environment. Using the descriptions provided in the metadata for the Utah State University coverage, descriptions for non-forested (Mattson and Despain 1985) and forested (Steele 1983) habitat used to create the GTNP coverage, and the vegetation categories of the NER coverage, vegetation categories from each coverage were matched up as accurately as possible.

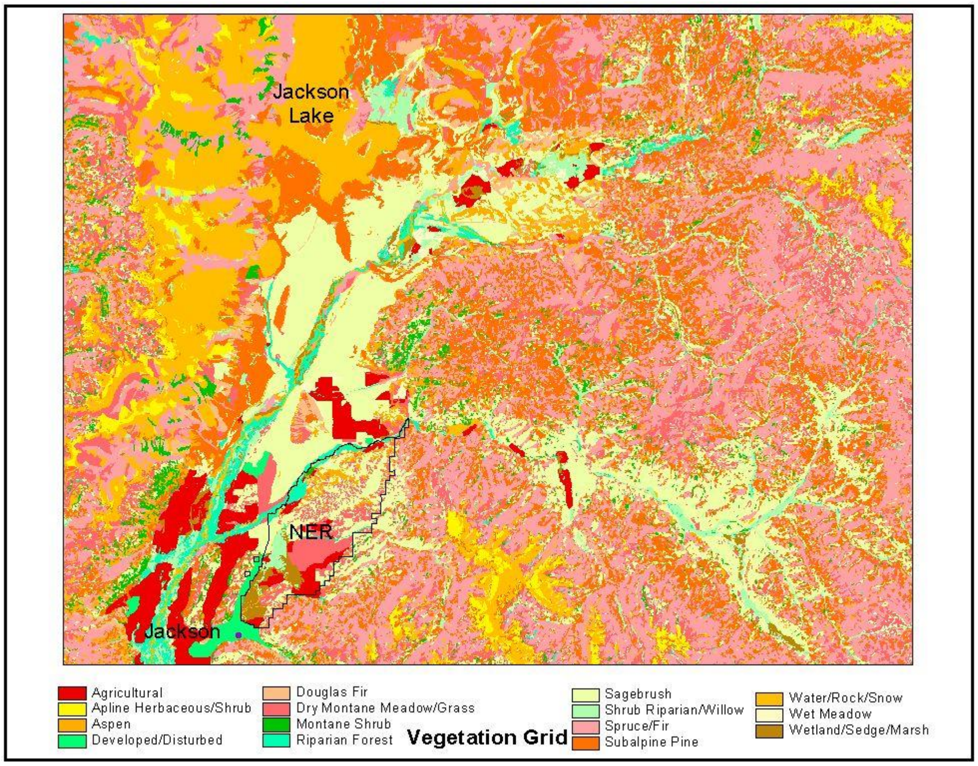

Figure 4. By using a cross-walk of vegetation categories, we combined data from three coverages to produce a single map representing 15 vegetation categories.

Data on annual production for each vegetation type were obtained from studies conducted by Biological Resources Division (BRD)--USGS, National Elk Refuge (NER)--USFWS, and Bridger-Teton National Forest (BTNF)--USFS. Each data set was collected in a different manner and so it was necessary to standardize the data so that they could be combined to create the largest data set possible for estimating average production values. Mean year, wet year, and dry year production values are given in Table 3 below. Wet year production equals 150% of the mean year; dry year equals 45% of the mean year. A detailed description of the methods used to derive these estimates are given in Appendix A.

Table 3. Vegetation Name and Production

Code	# of cells	Vegetation Name	Mean Production (pounds/acre)	Wet Year Production (pounds/acre)	Dry Year Production (pounds/acre)
1.	1158538.	Spruce/Fir	1162.	1743.	523.
2.	147739.	Douglas Fir	705.	1058.	317.
3.	834291.	Subalpine Pine	1167.	1751.	525.
4.	148500.	Aspen	1712.	2568.	770.
5.	68064.	Riparian Forest	2524.	3786.	1136.
6.	690177.	Sagebrush	1190.	1785.	536.
7.	147658.	Shrub Riparian/Willow	2125.	3188.	956.
8.	91805.	Montane Shrub	1708.	2562.	769.
9.	105584.	Alpine Herbaceous/Shrub	1693.	2540.	762.
10.	440890.	Dry Montane Meadow/Grass	895.	1343.	403.
11.	27067.	Wet Meadow	2385.	3578.	1073.
12.	34630.	Wetland/Sedge/Marsh	4760.	7140.	2142.
13.	457338.	Water/Rock/Snow	0	0	0
14.	117513.	Agricultural	2498.	3747.	1124.
15.	18881.	Developed/Disturbed	4334.	6501.	1950.

Spatial Heterogeneity of Forage and Initial Forage Availability

Managers raised a question about the spatial heterogeneity of production due to varying rainfall over the study area. For example, sagebrush on the NER may produce differently than sagebrush in the upper Gros Ventre drainage. We attempted to create a spatially explicit production map based on actual production measurements across the study area. However, these estimations did not yield significant spatial differences in production for each vegetation type. While we recognize that rainfall may vary across the area, and the production may vary with it, field data could not support these distinctions.

Although the production estimates in Table 3 represent total production on the landscape, a question was raised at a meeting of managers and modelers in Jackson in February 2002 about forage availability to ungulates. It was suggested that a significant amount of measured forage is totally unavailable to ungulates because it is unpalitiable or is obstructed by inedible plant tissue. Based on past experiences of measured offtake, meeting participants estimated this unavailability between 50% and 25%. Using elk offtake data gathered from the study area (Steele et al. 1999) and other offtake data from similar systems (Hobbs et al. 1996, Singer et al. 2002), we estimate this percentage to be 35%. Our model uses this estimation by initially decrementing the production values by 35% at the beginning of winter.

Snow Distribution

We predicted temporal and spatial variation in snow water equivalents (SWE) using a model developed by Michael Coughenour and Phil Farnes in the 1990's for Grand Teton National Park. The model uses input data from snow stations and interpolates among them to produce a surface of predictions. It was written as a broader precipitation model with the capabilities of predicting precipitation level, snow depth, and SWE, depending on various input and model switches. For the current modeling effort, we used SWE because it is the primary determining factor for ungulate migratory behavior. A detailed description of implementation of the snow model and corrections developed for the Gros Ventre snow shadow are presented in Appendix B.

Ungulate Offtake

The model requires estimates of the total amount of forage consumed by elk, bison, and moose on the study area. We calculated offtake assuming that each animal consumes dry matter equal to 2% of its body mass each day (Cordova et al. 1978, Baker and Hansen 1985, Baker and Hobbs 1987). We estimated an average body mass for each ugulate species weighted by the sex and age composition of their current populations. Animal age/sex counts were obtained from participating state and federal wildlife agencies. Average weights for each species and for each age/sex class were gathered from literature (Meagher 1973, Houston 1982). A sample of the spreadsheet calculations used to estimate these weighted averages appear in Appendix C: Table 4.

Model Overlays

The model overlays a SWE grid on the vegetation grid during each time step. For example, when snow accumulation is relatively light, the model allows foraging over large areas of the winter range (Figure 5). However, when snow accumulation is heavy, there are very few areas that are open for foraging (Figure 6).

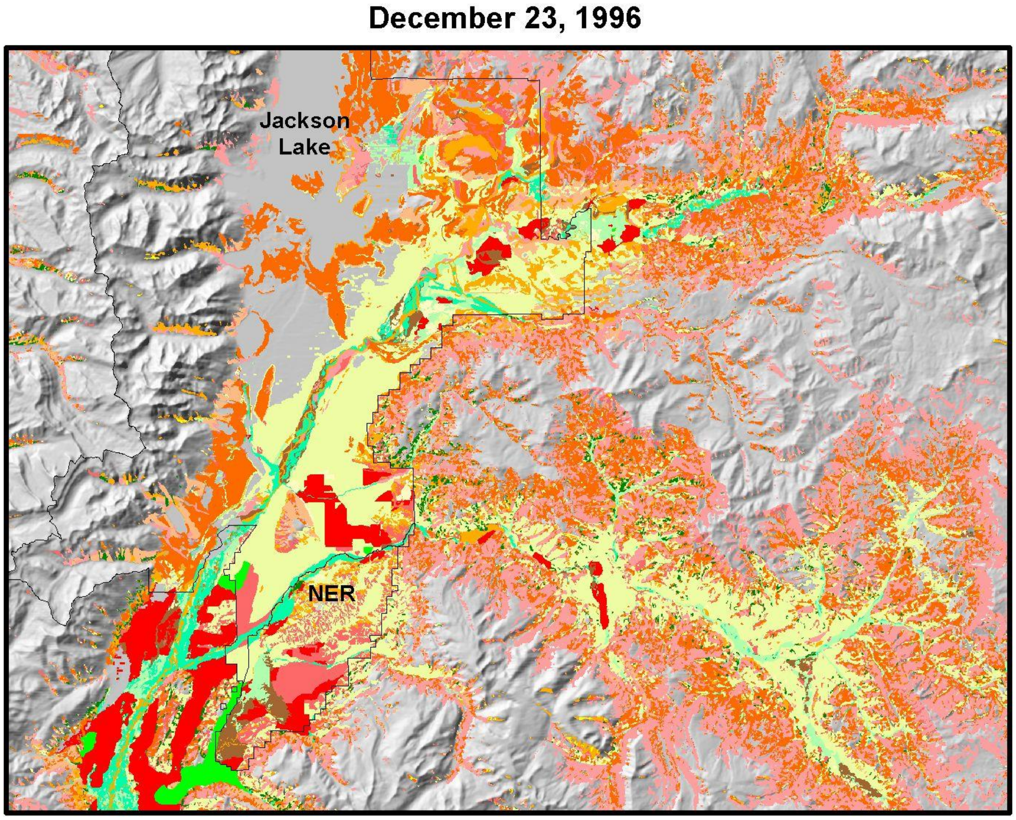

Figure 5. Overlay of snow accumulation ≥ 6 inches SWE on the vegetation map for December 23, 1996. Grey shading indicated areas of the landscape with ≥ 6 inches SWE. (Map adjusted for Gros Ventre snow correction.)

March 8, 1997

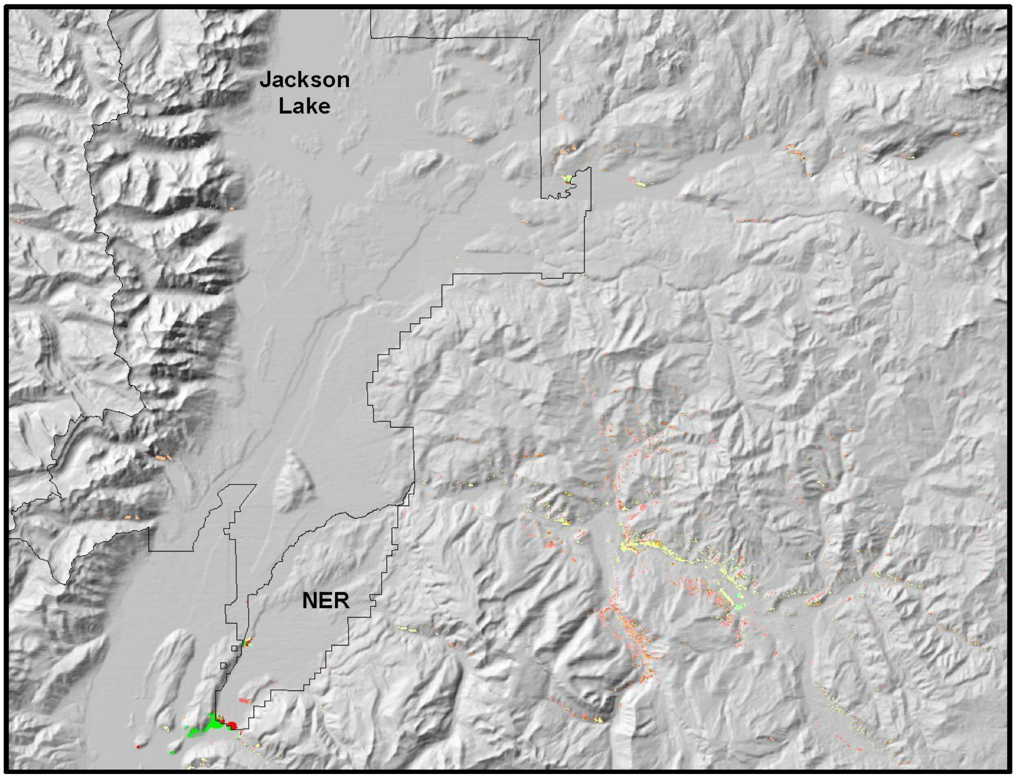

Figure 6. Overlay of snow accumulation ≥ 6 inches SWE on the vegetation map for March 8, 1997. Grey shading indicates areas of the landscape with ≥ 6 inches SWE. (Map adjusted for Gros Ventre snow correction.)

Modeling Scenarios

We exercised the model on both study areas -- the Greater Teton Ecosystem, and the NER (Figure 1). Within each study area we ran a series of simulations accounting for 1) varying populations of elk -- between 0 and 18,000, 2) varying SWE winters -- average, above average, and severe, 3) varying pre-winter precipitation conditions -- drought, mean, and wet, and 4) varying populations of bison as specified by the EIS Alternative's assumptions. On the Greater Teton Ecosystem, the model runs include offtake for 890 moose. On the NER, the model runs include offtake for 20 moose. On the Greater Teton Ecosystem, we varied elk populations between 0 and 18,000 animals, and ran enough simulations to get the shape of a trendline following the data points. On the NER, we varied elk populations between 0 and 10,000. Wintering bison populations have been growing very quickly in the valley. In 1999 there were roughly 500 bison in the study area whereas in 2002 the number was 650.

We varied winter severity using three types of winter snow conditions: average, above average, and severe. We chose 1996 as an example of an average winter, 1982 as a moderately severe winter, and 1997 as a severe winter. These choices were justified by consulting Farnes et al. (1999) which presents a table of estimated mean SWE for the 50-year recording period in the Hunter-Talbot hayfields. Using Farnes' table, we ranked snow severity using the SWE measurement on the hayfields. 1996 came in as the mean ranking while 1982 was above average. Although four winters prior to 1980 had data which was more severe than 1997, our snow data set only went back to 1980. Thus we used 1997 as the "most severe on record". We also consulted with Farnes and got agreement about using these representative years. In addition to this ranking, we also calculated average areas open per day during the 6 snowiest weeks of each winter. Table 4 presents the areas open to ungulates, i.e., that have less than 6 inches of SWE for each winter.

Table 4. Average Acres Open per day in the six snowiest weeks of each winter

Acres Open (< 6" of SWE)	
Whole Study Area	
1996 – Average	50,947
1982 – Above Average	19,649
1997 – Severe	12,003
NER only	
1996 – Average	8,531
1982 – Above Average	2,560
1997 - Severe	690

Model Results on the Greater Jackson Ecosystem for EIS Alternative #1 (status quo)

We estimate the margin of error for the results in the Greater Teton Ecosystem to be ± 20%. We cannot firmly quantify this error, but believe, based on our expertise derived from similar systems, that ± 20% is a reasonable approximation.

These results should not be used as the sole factor in determining the appropriate numbers of elk and bison on the Teton ecosystem or the NER. Instead, these results should be used as a starting point for management decisions, and used along with other pertinent factors such as long-term local knowledge, the results of other research, and management objectives not factored into this modeling effort. We do not interpret these results as the "carrying capacity" of the landscape, nor do we support an interpretation that assumes specific levels of mortality based on forage deficits. "Carrying capacity" is a complicated ecological concept that is not directly addressed by this model, and mortality estimates are provided in Part III of this report.

Throughout this report, we refer to graphs of forage deficits as a function of elk population size. These graphs show how forage deficits change and elk numbers increase given a range of assumptions about weather and the abundance of bison. In evaluating the forage deficit graphs, we refer to the point where each line intersects the x-axis as the point where forage offtake exactly equals forage supplies. This point gives a reasonable estimate of the number animals needed to unbalance the forage supply/forage demand equilibrium. As populations increase above this level, that is, to the right of this intersection point, forage deficits will increase and forage requirements exceed supplies. Although forage deficits and an imbalance may occur, we do not suggest that mortality always follows. Elk are known to rely on stored energy reserves to survive winters and therefore can likely incur small forage deficits without starving.

Forage Deficits

Assumptions in Alternative #1 are "status quo", i.e., that management actions will be the same in the future as in the past. Flood irrigation will continue on the cultivated fields of the NER, elk will be able to browse the willow stands on the NER, and bison numbers will grow unregulated.

Figures 7 – 9 below depict forage deficits for Alternative # 1 under varying model conditions. Figure 7 depicts drought conditions, Figure 8 depicts mean precipitation conditions, and Figure 9 depicts wet precipitation conditions. Each figure has three sets of colored lines: the black set represents the average winter, the green set represents the above average winter, and the red set represents the severe winter. Each color of lines is also represented by three line types: the solid lines are the model runs for 500 bison, the dashed lines are for 1000 bison, and the dotted lines are for 2000 bison.

In Figure 7 (drought conditions), the solid black line touches the x-axis at about 5,500 elk. Thus we can interpret that in an average winter with 500 bison, as elk populations reach 5,500 and higher, forage deficits will begin to occur. Similarly, in an average winter with drought conditions with 1,000 bison (the dashed black line), forage deficits begin at approximately 3,800 elk in the entire Jackson ecosystem. In an above-average winter with 500 bison (the solid green line), forage deficits begin to occur at about 1,800 elk. As winter severity and bison numbers increase, deficits occur with smaller and smaller numbers of elk. The drought scenario utilizes 45% of the forage available in the mean precipitation scenario.

Note in Figure 7 that the solid red line (the severe winter with 500 bison) does not touch the x-axis. This is because deficits will begin to occur even when elk numbers are 0 animals. These deficits occur because in any week, all the available forage is being consumed by the 500 bison and the 890 moose on the landscape. This situation occurs in several of the modeled scenarios for the severe winter with high bison numbers, and in milder winters when bison numbers are high. This is the forage deficit that results soley from bison and moose populations, assuming that there were no elk competing with them for forage.

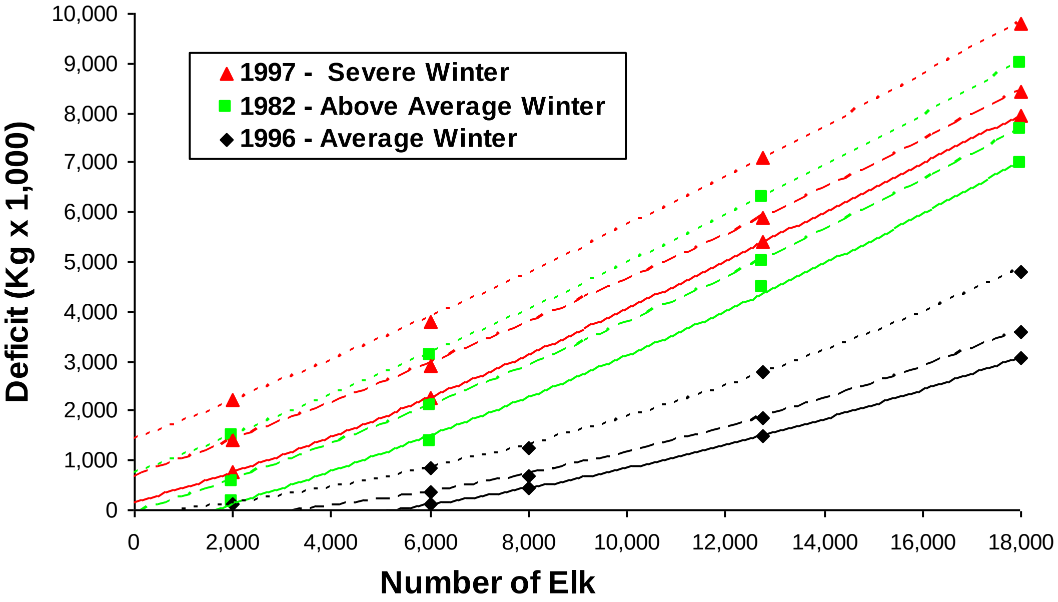

Figure 7. Drought scenarios for the Greater Teton Ecosystem -- Alternative #1.

Figure 8 depicts the modeled scenarios for mean precipitation conditions. The increase in precipitation causes significantly higher forage production across the landscape which translates into significantly more forage available to ungulates. Thus, compared to the drought scenarios, forage deficits occur at much higher numbers of elk across all model runs. In the average winter with 500 bison (the solid black line), forage deficits occur at about 16,000 elk. In the above average winter with 500 bison (the solid green line), forage deficits occur at about 6,000 elk. The severe winter causes deficits to occur at much lower numbers of elk, about 1,000 with 500 bison. As in drought conditions with severe winters and high bison numbers, deficits occur at 0 elk.

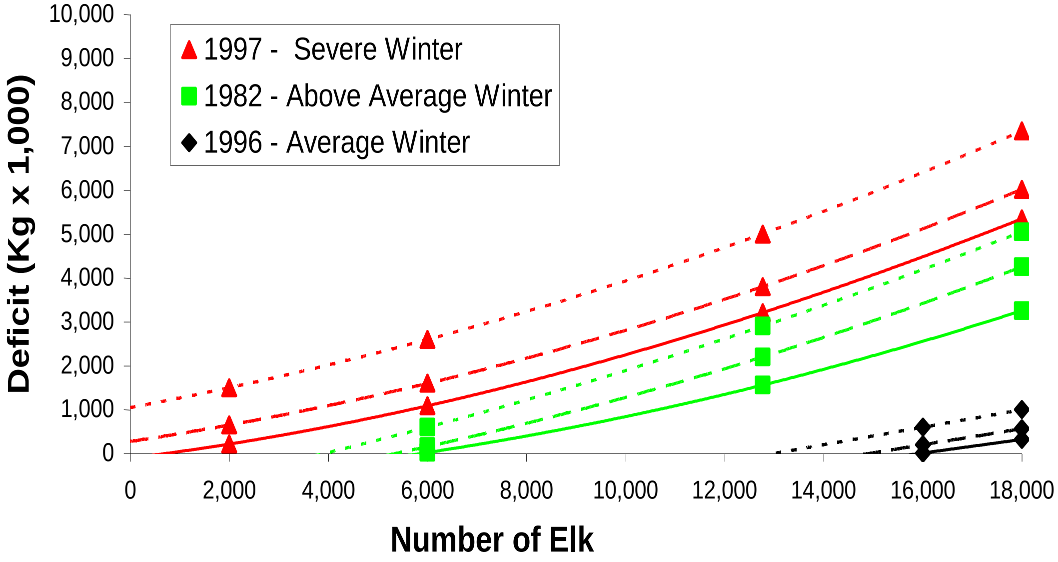

Figure 8. Mean precipitation scenarios for the Greater Teton Ecosystem -- Alternative #1.

Wet precipitation conditions (Figure 9) increase forage availability which similarly decreases forage deficits. In the wet precipitation scenarios, no deficits occur for any modeled population size of elk and bison in the average winter. In the above average winter with 500 bison, deficits occurred at 12,000 elk. In the severe winter with 500 bison, deficits started with 3,000 elk.

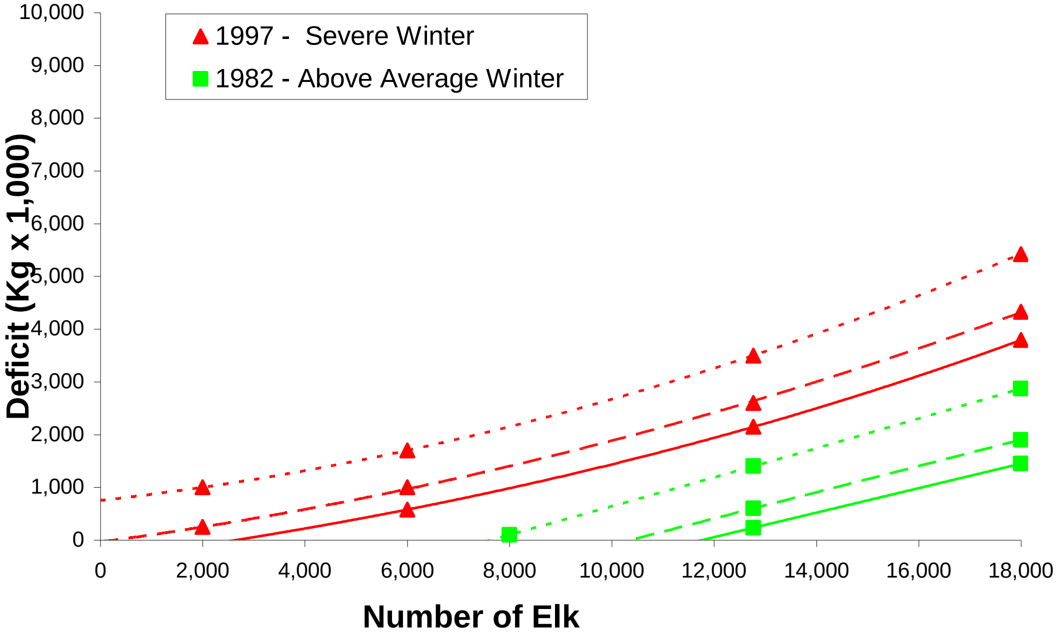

Figure 9. Wet precipitation scenarios for the Greater Teton Ecosystem –Alternative #1.

Forage Utilization

Forage utilization is simply the percent of forage removed from a given location in the study area as predicted by the forage accounting model. Managers are often concerned about forage utilization because high utilization can be construed as a measurement of habitat degradation. Here, we briefly describe utilization results, while leaving a quantified analysis of utilization effects for Part II of this report, “The Century Ecosystem Model”.

For the utilization results, we held precipitation and bison variables constant, and varied the number of elk and winter severity. We estimate that between 42 and 155 km^2 of winter range will be used in excess of 50% in an average winter with 500 bison and with elk populations of 6,000 to 18,000 (Figure 10). Utilization area increases in the average winter because rising numbers of elk push out and onto low-SWE areas of the range. During above average and severe winters, we estimate between 61 and 105 sq km of winter range will be used in excess of 50%. As elk numbers rise in above average and severe winters, utilization area actually levels off. This effect occurs because snow is blanketing the landscape and prohibiting elk from moving onto outlying areas. As long as elk populations are above ~14,000 animals, more severe winters will protect forage from being highly utilized. It should be understood however, that this reduction in utilization will lead to increased deficits and probably lead to a sharp increase in starvation mortality.

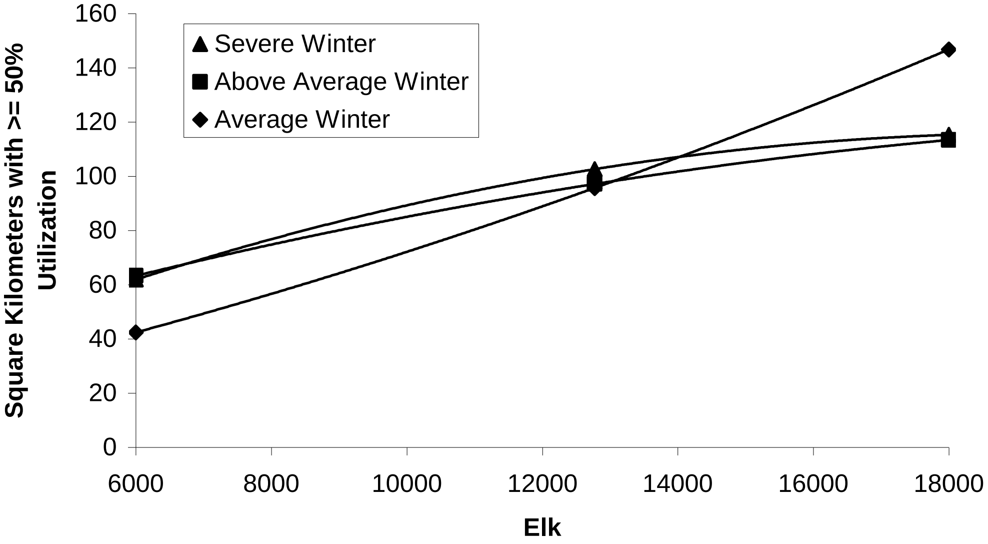

Figure 10. Area of winter range with utilization levels $\geq$ 50% as a function of elk population size during three winters with mean precipitation and 500 bison.

As an example of one utilization map, Figure 11 depicts forage utilization for the Greater Teton Ecosystem under a scenario of 12,771 elk, 500 bison, mean pre-winter precipitation in an average SWE winter. Although the maps will all differ slightly depending on winter severity and elk numbers, this map is indicative of the general layout of utilization across the Teton ecosystem. The black areas represent utilization of 50% or greater on the landscape which corresponds with areas that receive the least snow coverage during the winter.

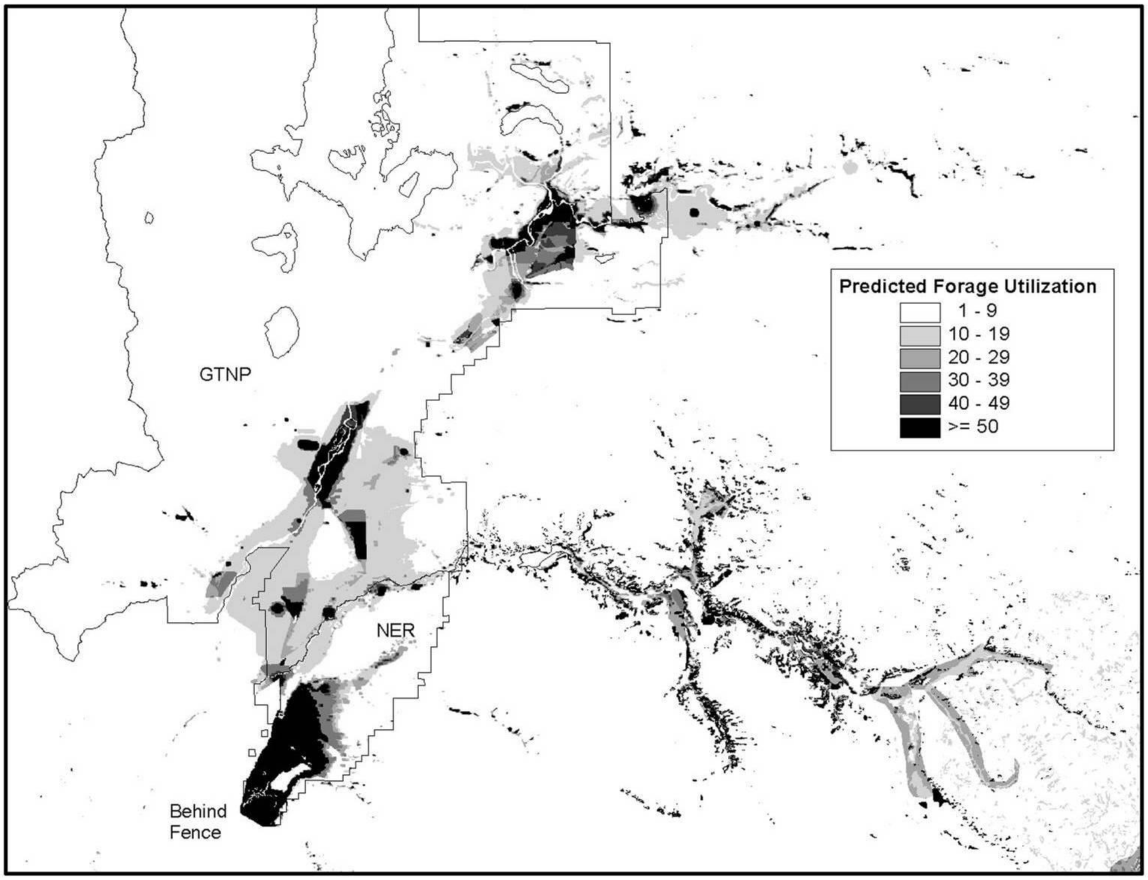

Figure 11. Predicted forage utilization for 12,771 elk in an average winter with average pre-winter precipitation and 500 bison.

Effects of Development in the Town of Jackson

One justification for supplemental feeding of elk is that it compensates for forage that would be available to native ungulates if their winter range had not been developed by human settlement in the town of Jackson. Although this justification is widely offered, it is based on a largely untested assumption of parity in the amount of forage fed and the amount lost to development. We analyzed this assumption as follows: If the development in the town of Jackson were exactly compensated by supplemental feeding, then adding the forage lost when the town was developed to the natural forage available to the currently supported population should theoretically *remove* the forage deficit. If supplemental feeding overcompensates for the development of the Jackson area, then forage deficits should remain despite "adding" the Jackson town forage base back into current supplies. If supplemental feeding undercompensates, then a forage surplus should result by adding the town of Jackson forage base back into the forage available to ungulates.

We ran two scenarios. We refer to the first scenario as "without fence." This scenario assumed that elk would no longer be restricted to habitat north of the fence on the National Elk Refuge and would be allowed to use agricultural lands and native pastures in and around Jackson. To implement this scenario, we simply added the forage in these areas to the forage supplies in the base model runs. The area added is the white area in Figure11 -- "Behind Fence".

We refer to the second scenario as "presettlement." In this scenario, we modified the current vegetation to reflect patterns that were more likely before agricultural development of the Jackson

Valley (irrigation, seeding, fertilization, etc.) As an approximation of these conditions, we assumed that vegetation south of the wildlife fence was composed of roughly equal parts of wet meadow and sagebrush-grassland.

Model results (Figure 12) suggest that at 2,000 elk in the severe winter, forage deficits are reduced by 51% (from 217,000 kg to 110,000 kg) when forage is added south of the fence. However, at 18,000 elk, this reduction shrinks to 13%. Similarly for the presettlement scenario, at 2,000 elk in the severe winter, deficits are reduced by 26%, but shrink to 6.2% at 18,000 elk. Because elk numbers are currently around 12,000 – 14,000, it is safe to say that the area south of the fence, reaching to the bottom of the study area, will not provide adequate forage for elk in severe winters. If high populations of elk need to find adequate forage in severe winters, they would more likely need to migrate further south down the Snake River drainage. Forage deficits are completely offset in the average winter, even at 18,000 elk. However, the "with fence" deficits were small in the average winter, so the offset is less meaningful.

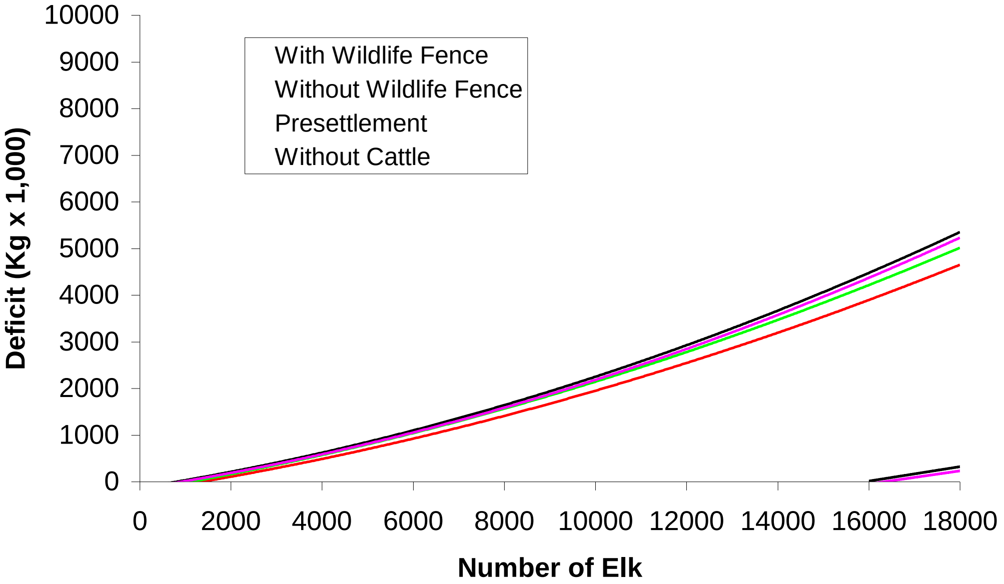

Figure 12. Forage deficits predicted under different assumptions about effects of the town of Jackson, and without cattle offtake. The model was run on severe and average winters with mean precipitation and 500 bison. Severe winters are depicted by the four lines which cross the x-axis at ~1,000 elk; average winters are depicted by the two lines which cross the x-axis at ~16,000 elk. The "with fence" scenario assumes no forage use by native ungulates south of the wildlife fence. The "without fence" scenario assumes that native ungulates are able to use vegetation south of the wildlife fence as currently mapped. The "presettlement" scenario assumes that native ungulates are able to use vegetation south of the wildlife fence and that this vegetation is composed of 50% sagebrush and 50% wet meadow. The "without cattle" scenario assumes no cattle grazing on the Greater Teton Ecosystem.

Removal of the Wildlife Fence

A model run that accurately portrays the spatial effects of removing the wildlife fence is not feasible with current data and understanding. If the fence were removed and feeding were discontinued, the Jackson elk herd would probably migrate south of Jackson and intermingle with other herds from which they have been separated for many years. We are able to offer two general scenarios that shed light on the effects of removing the wildlife fence and cessation of feeding. First, the graphical depiction of the "without fence" scenario discussed in Figures 12 corresponds to the visual representation of utilization in and around the town of Jackson depicted in Figure 13 below. Utilizations would cover the town of Jackson at the >50% level, and would be constrained only by the elevational gradient that exists around the town.

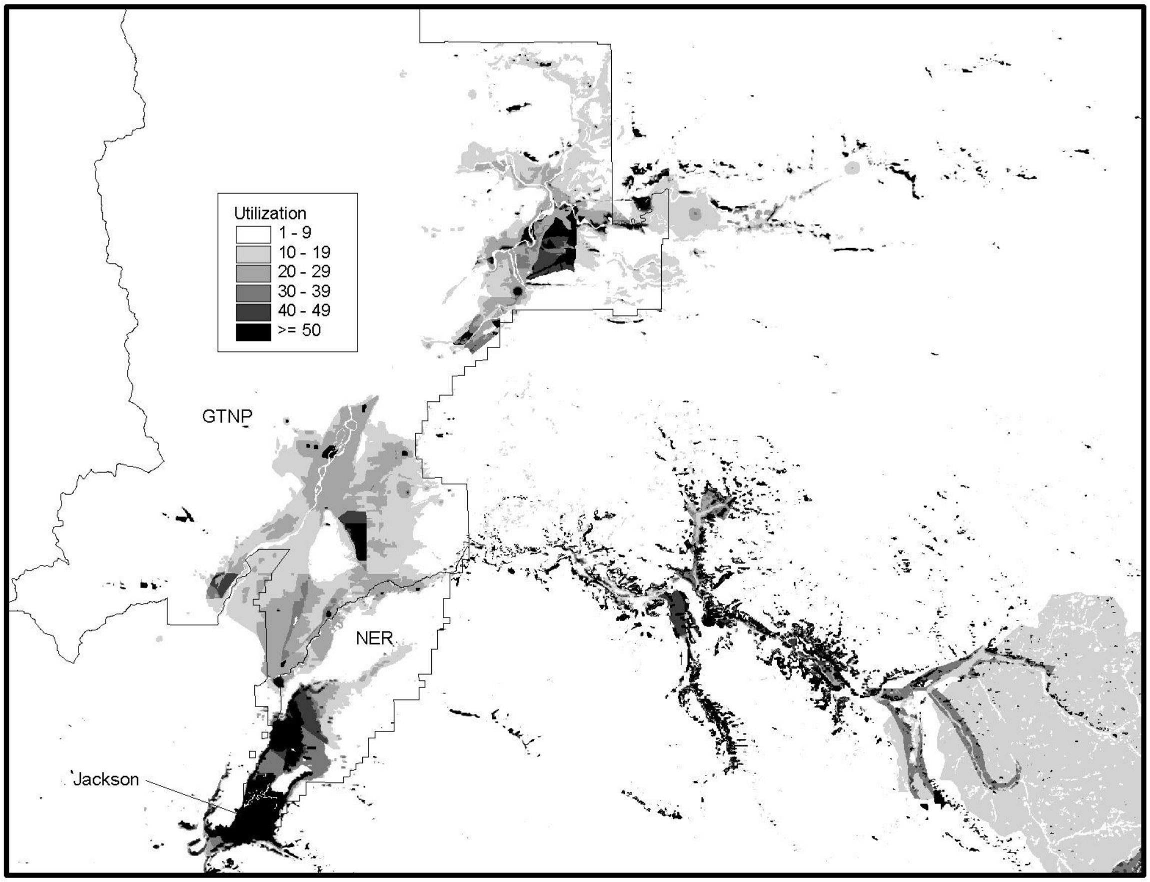

Figure 13. Utilizations in an average winter with average precipitation and 12,771 elk without the wildlife fence. Very high utilizations would likely continue south of the NER into the town of Jackson.

Second, we ran the snow model on a larger area and corrected it for the Gros Ventre snow shadow (Figure 14). The black cells on the map depict areas with 6 inches or less of SWE on March 8, 1997, the snowiest day available in the database. Results indicate that elk could winter in the Gros Ventre valley or south of Jackson in the Snake River valley as it winds towards Alpine, and lower areas of Hoback Canyon.

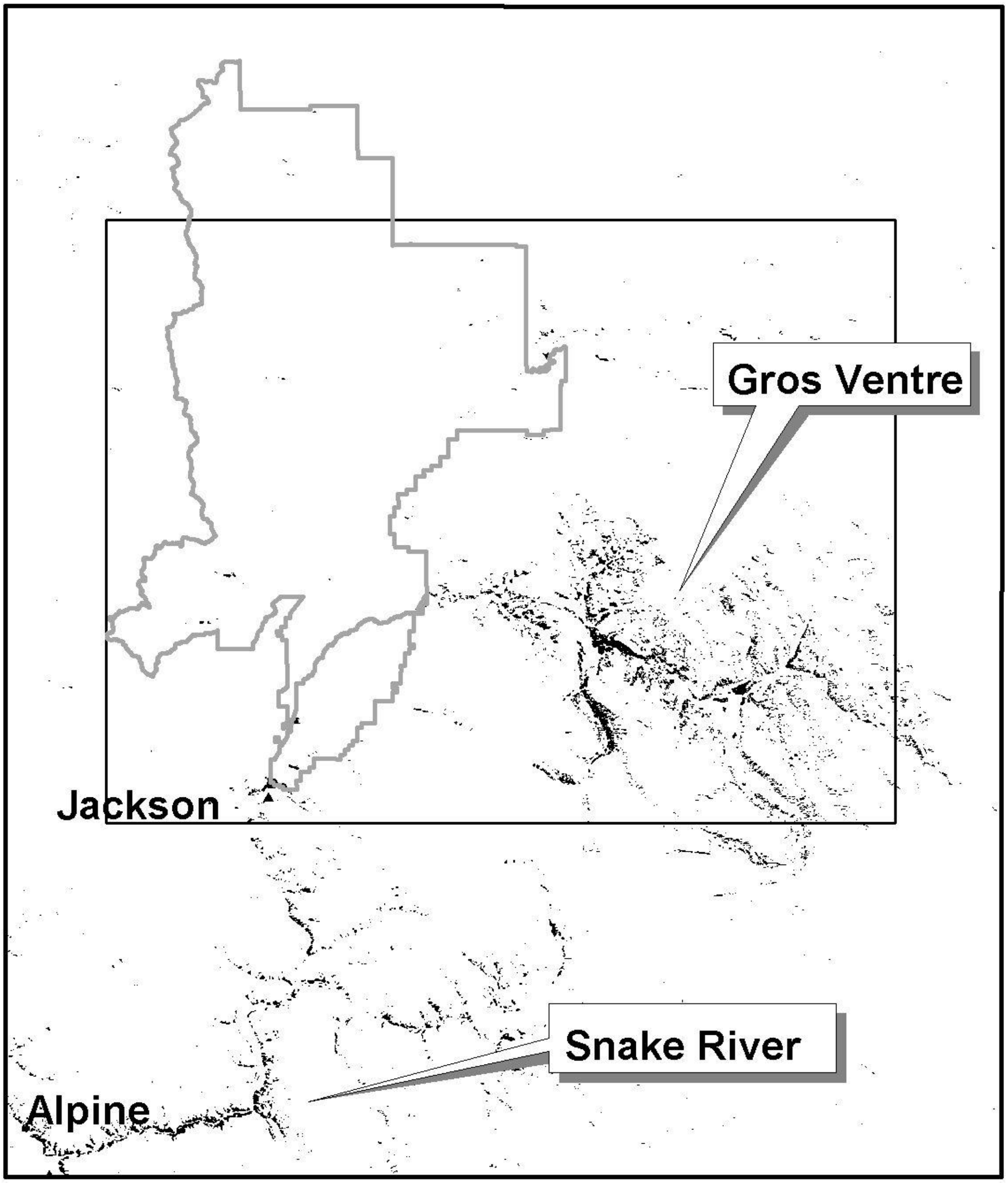

Figure 14. Black cells indicate likely migration routes and wintering areas in severe winters. The Gros Ventre and the lower Snake areas are predicted to receive the highest elk numbers and utilizations should the wildlife fence be removed.

Effects of Cattle Grazing

To examine the effects of cattle grazing on forage deficits we estimated the biomass consumed by cattle during summer and subtracted that from the prewinter standing crop. We did this by overlaying coverages of grazing allotments on the vegetation map, estimating the total forage removed as a function of the stocking rate, and subtracting that estimate from the prewinter forage supply. In addition, Steve Kilpatrick (WGFD), reviewed and offered small changes to the cattle offtake map.

The model runs (the purple lines on Figure 12) revealed negligible effects of cattle grazing on forage deficits for wild ungulates. Although the total amount of forage consumed by livestock was substantial -- about 0.5% of the total production on the Teton ecosystem -- most of this consumption occurred on areas that were not important elk winter range. As elk numbers increased, deficit differences with and without cattle became quantifiable (the difference between the black line and the purple line in Figure 12). At 18,000 elk, "with fence" deficits were 5,346,000 kilograms whereas "without cattle" deficits were 5,229,000 kilograms, a difference of 117,000 kilograms or 2.2%.

Model Results on the National Elk Refuge for Alternative #1

Adapting the Forage Accounting Model to the NER

The Forage Accounting Model was initially written to run on the Greater Teton Ecosystem utilizing the weekly SWE maps created by the snow model. These weekly snow maps are the factor which drives elk migration throughout the study area. To adapt the model to run only on the NER, we continued to use the snow maps as the migratory switch but we only allow elk to consume forage on the NER rather than on any area beyond the NER's borders. This forces all elk onto the NER's forage as soon as snow begins (roughly on Nov. 1st) and keeps them there until the end of snow (roughly June 1st). At the beginning of the snow season, the animals are allowed to spread out over the entire NER, but as snow accumulates, they are restricted to low SWE areas. As snow melts, they are allowed to spread out over the low-SWE areas on the NER.

Real migratory movements are likely to be different. In a real scenario, elk slowly move onto the NER as snow accumulates, and slowly move off as snow melts. Because our model cannot mimic these real movements, our numeric estimates of forage deficits are overly high, i.e., real deficits may be lower than those depicted in the following figures, and higher numbers of elk may be supported before deficits occur. For example, if deficits start at 6,000 elk, this can be interpreted as "at least" 6,000 elk are needed to incur deficits. While the actual number may be 7,000 or 8,000, it is definitely not 5,000. Thus, the margin of error for the NER should be construed differently than for the Greater Teton Ecosystem. On the NER, deficit predictions represent the lowest limit in the margin of error. We roughly estimate the upper limit as the lower limit plus 50%. Again, we cannot firmly quantify this error but believe it is a reasonable approximation.

Modeled Scenarios

For Alternative #1, we exercised the forage accounting model on the National Elk Refuge and ran simulations for 1) varying populations of elk -- between 0 and 10,000, 2) varying winter severity -- average, above average, and severe, 3) varying pre-winter precipitation conditions -- drought, mean, and wet, and 4) three populations of bison -- 500, 1000, and 2000. These model runs include offtake by 20 moose. We also ran a scenario which simulates center-pivot irrigation of 1,170 acres of the cultivated fields on the NER which are currently flood-irrigated.

In Figure 15 (severe drought conditions), the solid black line touches the x-axis at about 2,000 elk. Thus we can interpret that in an average winter in drought conditions with 500 bison, as elk populations reach 2,000 and higher, forage deficits will begin to occur on the NER. Note in Figure 1 that all of the other lines do not touch the x-axis, i.e., deficits occur even when elk numbers are 0 animals. These deficits occur because in any week, all forage is being consumed by the 500 bison and the 20 moose.

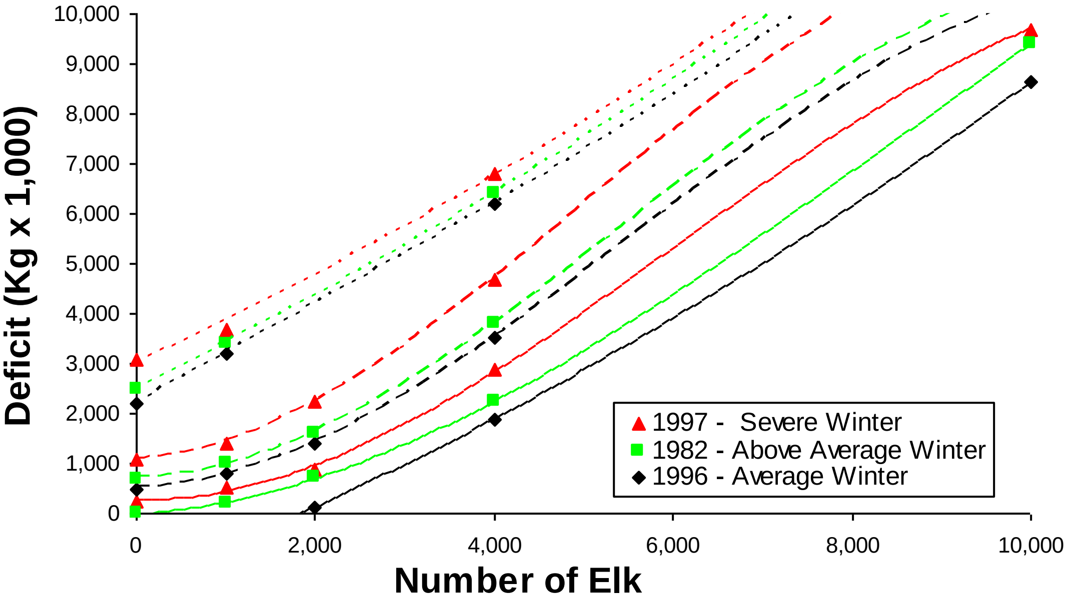

Figure 15. Forage Deficits for Drought Conditions on the NER.

Figure 16 depicts the modeled scenarios for mean precipitation conditions which create significantly more forage for ungulates and cause deficits to occur at much higher numbers of elk in average winters. With 500 bison in the average winter (the solid black line), forage deficits occur at about 5,000 elk, occur at about 4,000 elk with 1,000 bison, and 2,000 elk with 2,000 bison. Though mean precipitation increases forage production, there is still sufficient snow in above average and severe winters to incur deficits at 0 elk across all bison numbers.

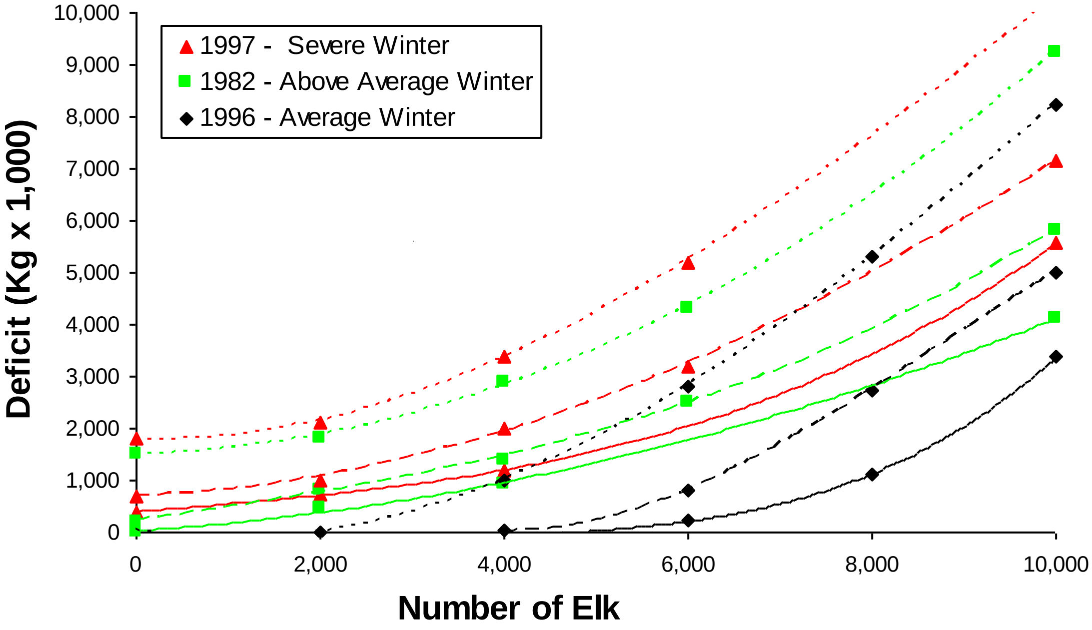

Figure 16. Forage Deficits for Mean Precipitation Conditions on the NER.

Wet precipitation conditions (Figure 17) increase forage availability which similarly decreases forage deficits. In the wet precipitation scenarios, deficits occur at roughly 9,200 elk in the average winter and 800 elk in the above average winter with 500 bison. Severe winters still cause deficits to begin at 0 elk due to the extreme snow cover on the landscape.

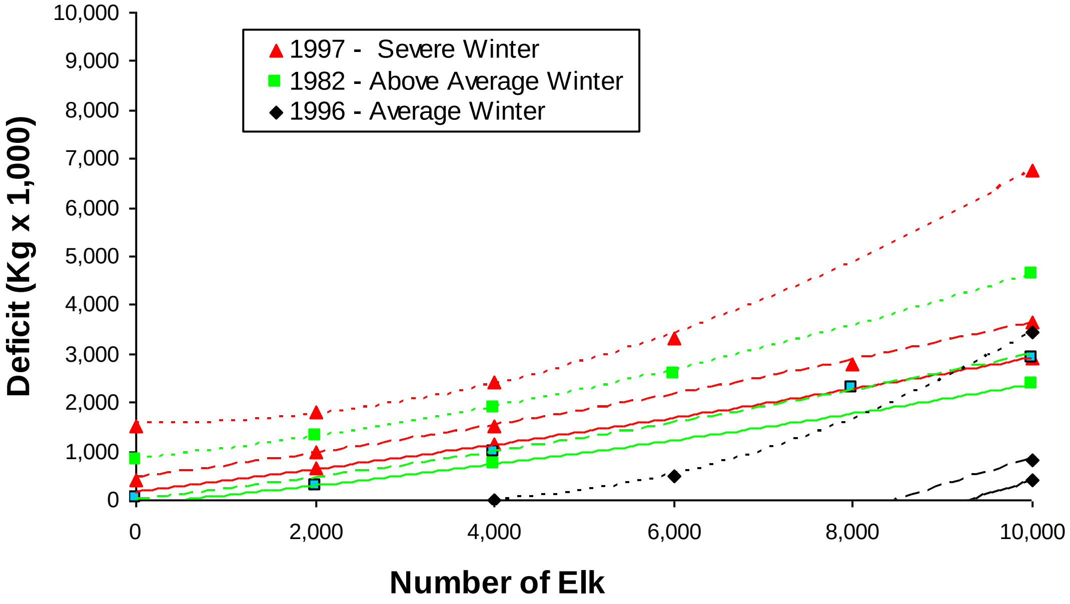

Figure 17. Forage Deficits for Wet Precipitation Conditions on the NER.

Irrigation Experiment

We created an additional model experiment to address an questions on the value of irrigation on the NER. Managers may want to center-pivot irrigate ~1,170 acres of the NER to raise production, thereby increasing the biomass of forage available to wintering elk. As per the description in the document "Irrigation System Rehabilitation Plan Environmental Assessment" (National Elk Refuge, October 1998), we created a model scenario in which production values on the following NER project areas were increased to reflect center-pivot irrigation: McBride, Chambers, Nowlin, Ben Goe, and Headquarters (Figure 18). Currently these areas are flood-irrigated resulting in about 2,500 lbs/acre of production whereas center-pivot irrigation will result in about 5,000 lbs/acre. For this experiment, we varied only the irrigation acreage, holding precipitation and bison constant (average precipitation and 500 bison).

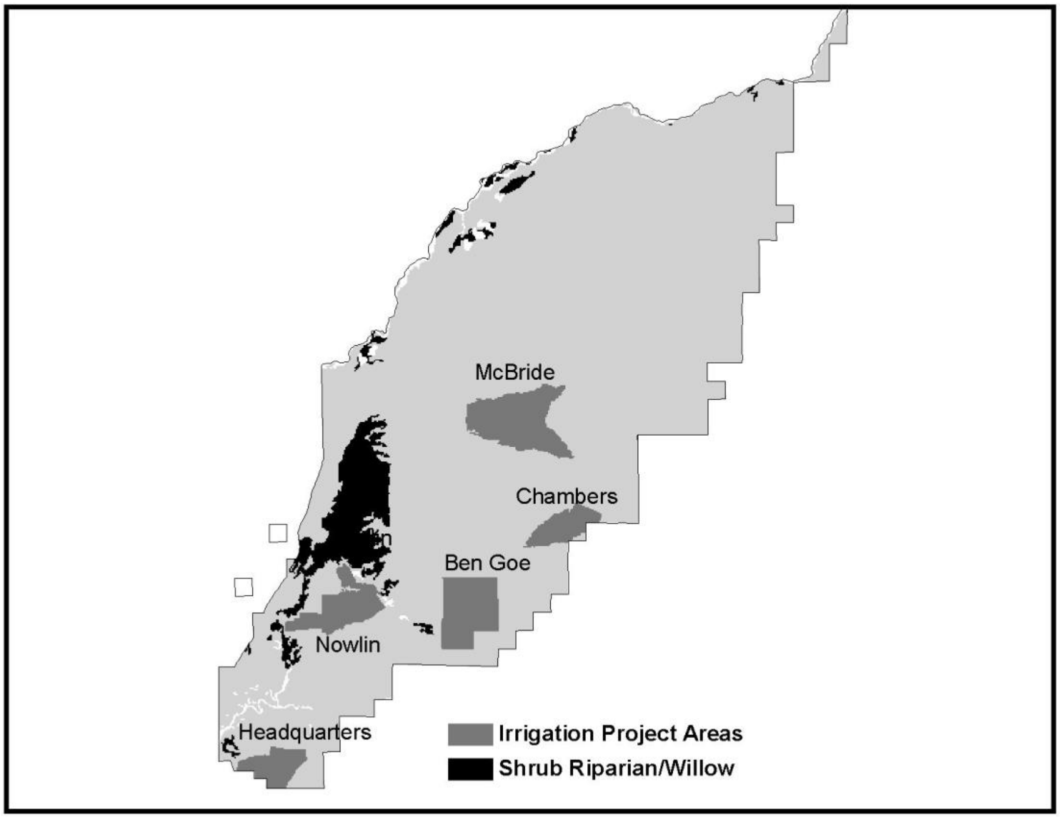

Figure 18. Irrigation Project Areas and willow locations on the NER.

As shown in Figure 19, center-pivot irrigating the four NER project areas has a significant impact on forage deficits in an average winter under average precipitation with 500 bison (solid lines). For the flood-irrigated scenario in the average winter, deficits begin at about 5,000 elk and are 3,371,000 kilograms at 10,000 elk. For the center-pivot irrigated scenario, deficits begin at about 6,000 elk and are 2,207,000 kilograms at 10,000 elk. In a severe and above-average winter, the change in deficits is less pronounced. All irrigation scenarios have deficits beginning right at 0 elk, and as the number of elk increases, a slight difference exists between the two scenarios, culminating in a deficit of 5,560,000 kilograms at 10,000 elk for the flood-irrigated scenario and a deficit of 4,711,000 kilograms for the center-pivot irrigated scenario. With center-pivot irrigation, the average winter yields more deficit reduction because more of the range is open to ungulates. In the severe and above-average winter, the upper NER irrigated project areas are covered in too much snow at critical weeks during the winter.

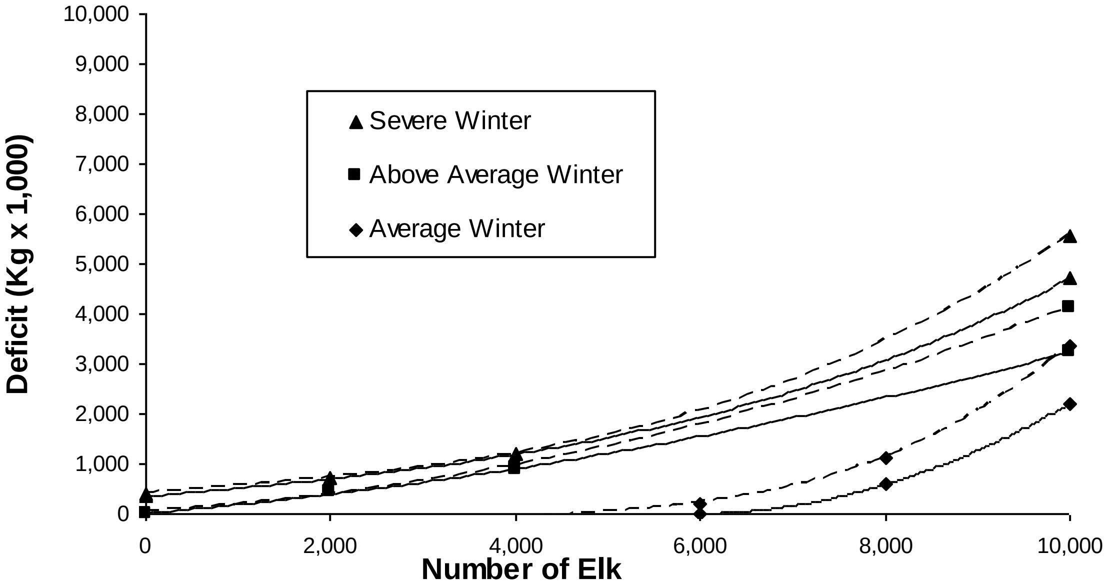

Figure 19. Forage Deficits for the Irrigation Model Experiment on the NER. Solid lines represent center-pivot irrigation; dotted lines represent flood (status-quo) irrigation.

Discussion for Alternative #1

Our model revealed that balance between forage supply the forage requirements of wintering ungulates are tightly linked to winter severity and growing season precipitation. Although both of these weather conditions can determine the number of animals that can be supported by native forage, snow accumulation exerts the strongest effects. During average winters with average precipitation conditions and 500 bison, the number of elk that can be sustained on the landscape approaches 16,000. But as winter severity or drought are encountered, this number drops dramatically.

Currently, elk and bison are supplementally fed on the NER to alleviate food shortages caused by snow severity as well as drought conditions. Additionally, it is argued that supplemental feeding is needed to compensate for forage supplies lost to the area behind the NER's wildlife fence. Our model experiments suggest that the wildlife fence plays an important role by inhibiting migration and foraging for native ungulates, and that removing the fence would increase forage availability especially during average winters. However, our model predicts that significant forage deficits would still occur during more severe winters if the wildlife fence were removed and native ungulates were allowed to graze in and around the town of Jackson as well as on nearby agricultural lands. This suggests that historic elk populations: (1) may have been smaller than current ones, and/or (2) may have suffered high levels of mortality during severe winters, and/or (3) more likely have used lower elevation ranges south of Jackson and larger areas of the Gros Ventre.

The influence of grazing by livestock on forage supplies for native ungulates has emerged as a controversial question for managers in the Greater Teton Ecosystem. Our model experiments suggest that cattle grazing does not play an important role in determining availability of forage for native ungulates during winter. This is the case because the preponderance of livestock grazing occurs on areas of the landscape that accumulate deep snow during the winter. As a result, increasing forage on these areas by removing livestock grazing may increase forage biomass but it does not increase forage available to wintering ungulates. Removing cattle from the system had negligible impacts on predicted forage deficits.

We predict that approximately 100 km^2 of winter range will be utilized at a 50% rate or higher given current numbers of elk and bison, and varying climatic conditions. Part of this high level of use is caused by the wildlife fence because it inhibits natural foraging patterns and migration. However, we emphasize that as long as animals select areas that are relatively snow free in preference to areas where snows are deep, we should anticipate locally high levels of forage utilization on some sites. Although reducing population density can reduce the area of the landscape that falls into the "high-use" category, we project that some "hot spots" will occur at any reasonable level of population numbers. The effect of these forage utilization rates and hot-spots will be analyzed in the next section of this report -- Part II, The Century Ecosystem Model.

Bison numbers play an important role in forage deficits. Given the number of bison at the start of this project, 500, approximately 16,000 elk can forage on the whole system without incurring deficits in an average winter with average pre-winter precipitation conditions. When bison numbers double to 1,000, elk numbers drop to 15,000; when bison numbers quadruple to 2,000, elk numbers drop to 13,000. Doubling bison numbers to 1,000 also substantially increases forage deficits in more severe winters, and quadrupling bison numbers to 2,000 causes severe stress on the system during most climatic conditions.

The results for the NER should be evaluated differently than those for the Greater Teton Ecosystem. Instead of a mean estimation with a surrounding margin of error, the NER's results should be construed as "lowest possible number of elk" which correspond to the deficit measurement. On the NER Study Area, this number represents the lowest limit in the margin of error. We roughly estimate the upper limit as equal to the lower limit plus 50%.

Given this stipulation, we estimate that the NER can support at least 5,000 elk in average winters with mean pre-winter precipitation and 500 bison. In above-average and severe winters, deficits occur at all levels of elk except in the wet precipitation scenario. In our irrigation experiment, we found that 1,000 more elk could forage on the NER before deficits would occur in average winters with mean pre-winter precipitation and 500 bison, and that forage deficits would be reduced in severe winters especially with high numbers of elk.

Forage Accounting Model Results for all the EIS Alternatives

We were asked to run the model and provide results for Alternatives #1 - #4 in the EIS and also provide a summary table of where deficits begin for each Alternative given its underlying assumptions as follows:

Alternative #1: (status quo) Flood irrigation of the NER's cultivated fields. All of the NER's willow is available to ungulates. Three levels of bison -- 500, 1,000, 2,000.

Alternative #2: No irrigation of the NER's cultivated fields. All of the NER's willow is available to ungulates. Two levels of bison -- 250, 500.

Alternative #3: Flood irrigation of the NER's cultivated fields. Bison = 1,000. Two amounts of the NER's willow are available to ungulates -- none and one-half.

Alternative #4: Center-pivot irrigation of the NER's cultivated fields. Bison = 350. Two amounts of the NER's willow are available to ungulates -- none and one-half.

For all of the alternatives, the Forage Accounting Model was run on both the Greater Teton Ecosystem and the NER study area. The cautions for interpretation discussed for Alternative #1 in the previous sections also apply to the results for Alternative #2 - #4. In addition to these stipulations, please note that the model is not sufficiently sensitive to discriminate between some of the Alternatives and their underlying assumptions. For example, the difference between the forage offtake from 350 bison and 500 bison is so small that the difference between the deficit results from those runs is subsumed by the model's margin of error. Similarly, the difference between types of irrigation, and the question of willow exclusion, also offered results which were subsumed by the model's margin of error.

We report these results with both a summary table and deficit graphs. First, Table 5 reports the number of elk at which forage deficits begin to occur. The number in each cell represents the "equilibrium point" on the landscape at which the estimated forage supply exactly offsets demand by the elk population. This number is the point at which the deficit curve hits the x-axis. Higher numbers of elk will cause deficits to occur. When interpreting these numbers, keep in mind that it is almost assured that wintering elk can sustain small levels of forage deficits by using stored energy reserves (fat and lean body mass) to survive. Because of this, we suggest interpreting the numbers in the table together with the curves in the graphs that follow. If the deficit curve remains low (near the x-axis), i.e., < 500,000 kg, then wintering elk may be able to utilize stored energy reserves to survive rather than incur starvation mortality. In other words, small forage deficits can occur without causing high levels of starvation.

Table 5. Summary Table for number of elk at which forage equilibrium occurs for all EIS Alternatives

Alternative #1 (status quo)									
Pre-winter Precipitation Scenario	**Drought**			**Mean**			**Wet**		
Snow Severity Type	**Severe**	**Above**	**Average**	**Severe**	**Above**	**Average**	**Severe**	**Above**	**Average**
With 500 Bison									
Greater Teton Ecosystem	0	1,800	5,500	1,000	6,000	16,000	3,000	12,000	>18,000
NER only	0	0	2,000	0	0	5,000	0	800	9,200
- with center-pivot irrigation				0	0	6,000			
With 1,000 Bison									
Greater Teton Ecosystem	0	200	3,800	0	5,800	15,000	200	10,200	>18,000
NER only	0	0	0	0	0	4,000	0	500	8,500
With 2,000 Bison									
Greater Teton Ecosystem	0	0	1,500	0	4,000	13,000	0	7,800	>18,000
NER only	0	0	0	0	0	2,000	0	0	4,000
Alternative #2 (no irrigation of cultivated fields on NER)									
With 250 Bison									
Greater Teton Ecosystem	700	1,800	6,000	1,800	7,500	16,400			

NER only	0	0	2,000	0	0	5,700			
With 500 Bison									
Greater Teton Ecosystem	0	1,600	5,300	900	5,900	15,800			
NER only	0	0	1,700	0	0	4,500			
Alternative #3 (with 1,000 bison and flood-irrigation of NER's cultivated fields)									
No Willow on NER Available									
Greater Teton Ecosystem	0	0	3,000	0	5,000	14,000			
NER only	0	0	0	0	0	3,300			
One-half of Willow on NER Available									
Greater Teton Ecosystem	0	0	3,200	0	5,500	14,200			
NER only	0	0	0	0	0	3,500			
Alternative #4 (with 350 bison and center-pivot irrigation of NER's cultivated fields)									
No Willow on NER Available									
Greater Teton Ecosystem	0	1,600	5,700	1,500	7,200	17,000			
NER only	0	0	2,000	0	0	5,500			
One-half of Willow on NER Available									
Greater Teton Ecosystem	0	1,800	6,000	1,800	7,400	17,100			
NER only	0	0	2,500	0	200	6,000			

Graphical Model Results for the EIS Alternatives #2 - #4

Model Results for Alternative #2

Alternative #2 assumptions: 1) 250 and 500 bison, and 2) no irrigation of the cultivated fields on the NER, 3) all willow is available.

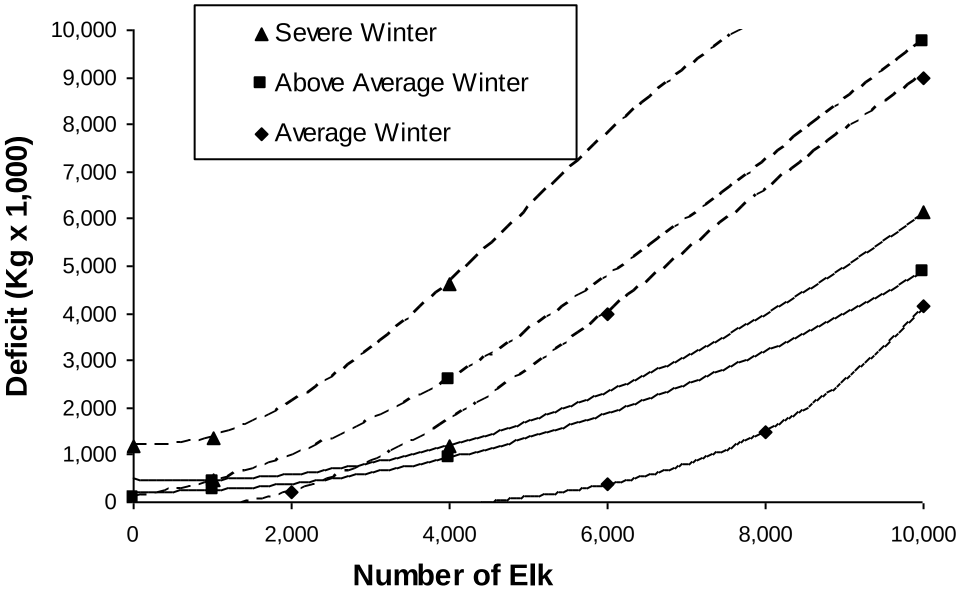

Figure 20. Deficit results for the NER using 500 bison. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

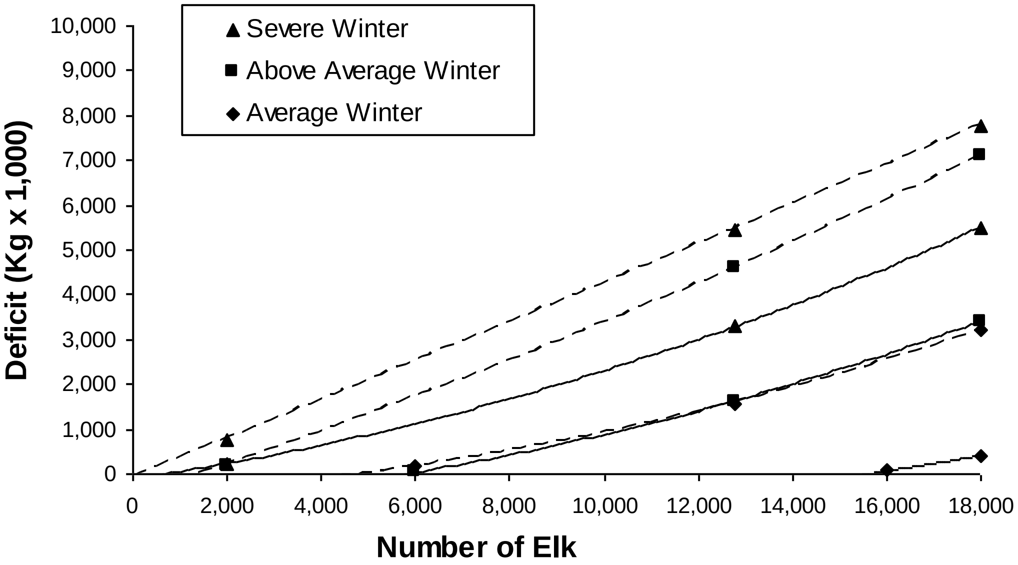

Figure 21. Deficit results on the Greater Teton Ecosystem using 500 bison. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

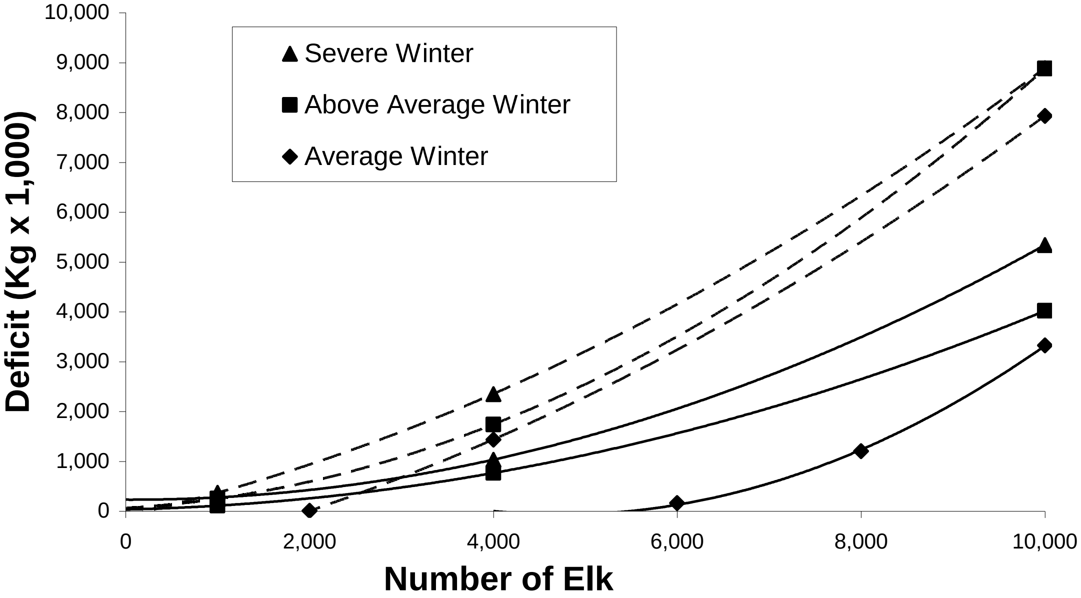

Figure 22. Deficit results for the NER using 250 bison. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

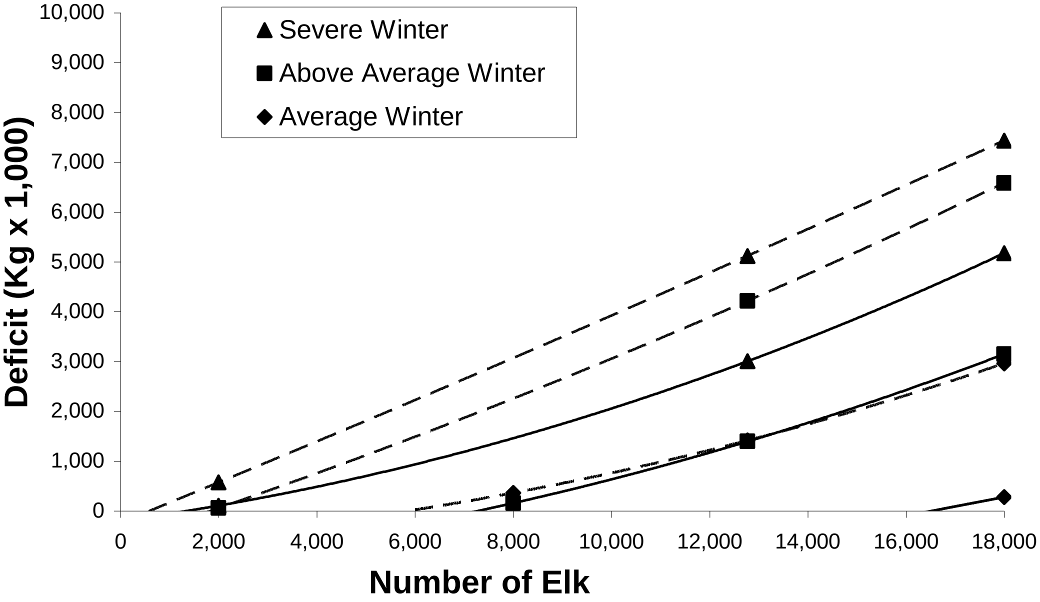

Figure 23. Deficit results for the Greater Teton Ecosystem using 250 bison. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

Model Results for Alternative #3

Alternative #3 assumptions: 1) 1000 bison, 2) cultivated fields on the NER are flood-irrigated (status quo), and 3) willow on the NER is all fenced off or half-fenced off.

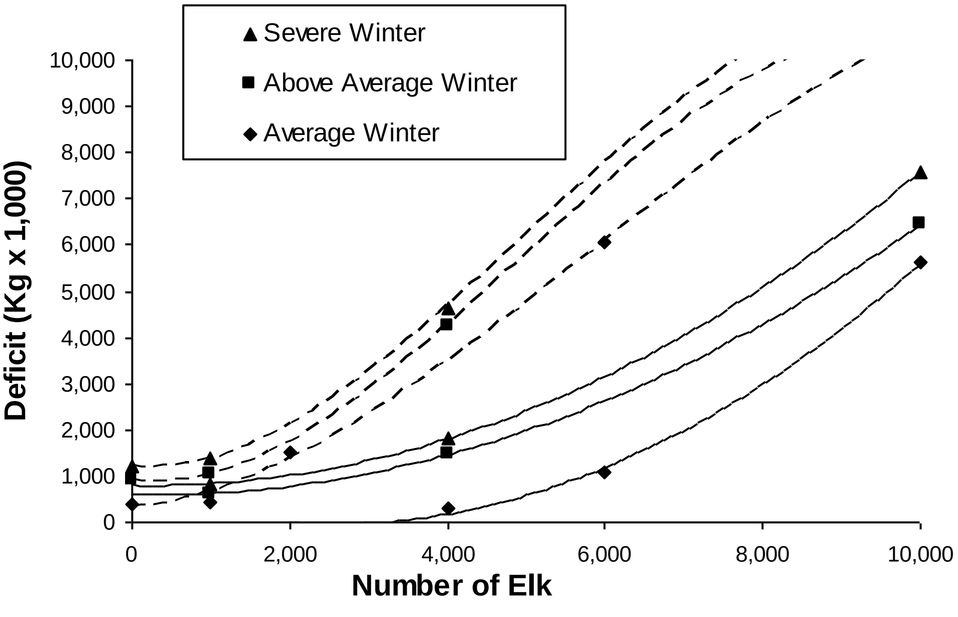

Figure 24. Deficit results for the NER with no forage available in vegetation coded "shrub riparian/willow". The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

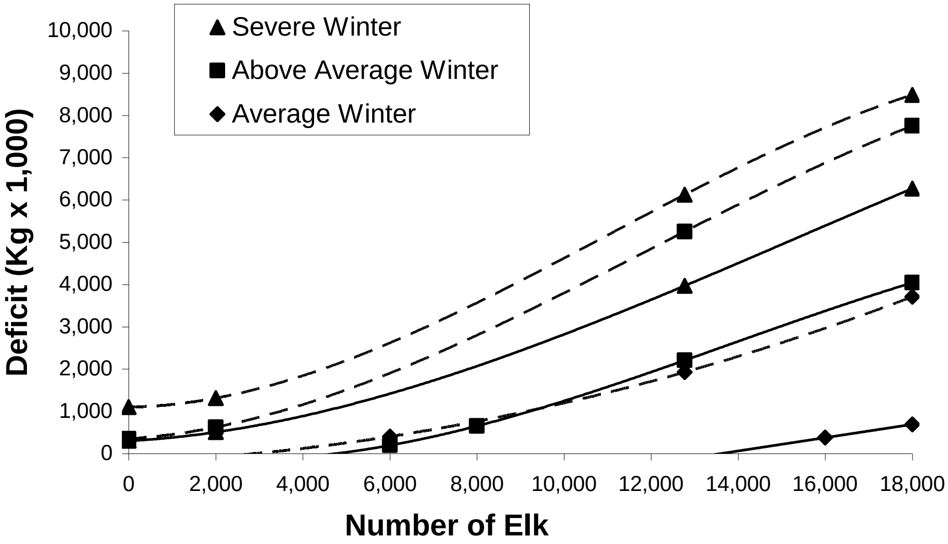

Figure 25. Deficit results for the Greater Teton Ecosystem with no forage available in vegetation coded "shrub riparian/willow" on the NER. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

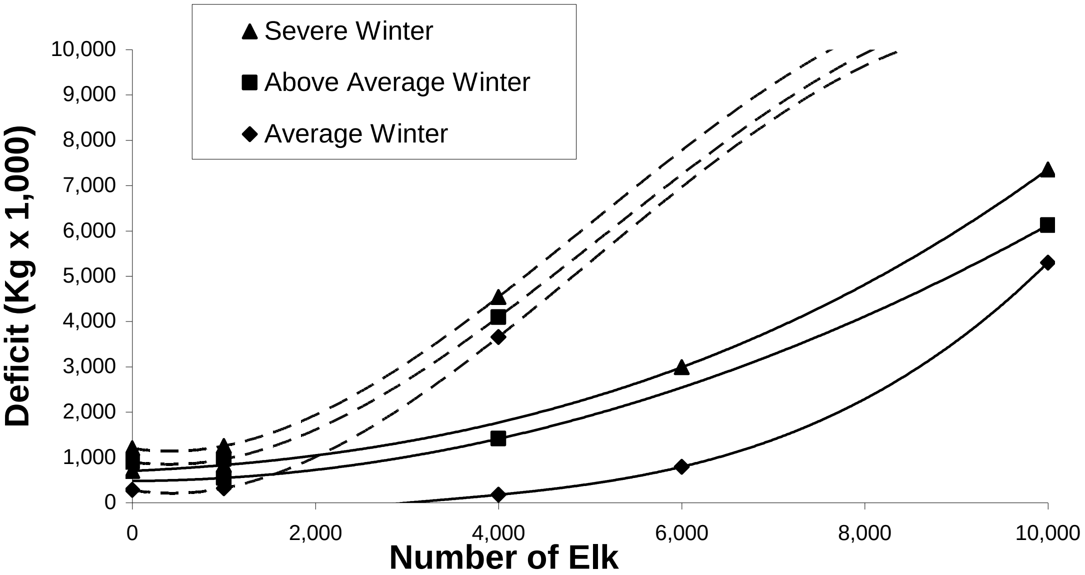

Figure 26. Deficit results for the NER with one-half of the forage available in vegetation coded "shrub riparian/willow". The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions

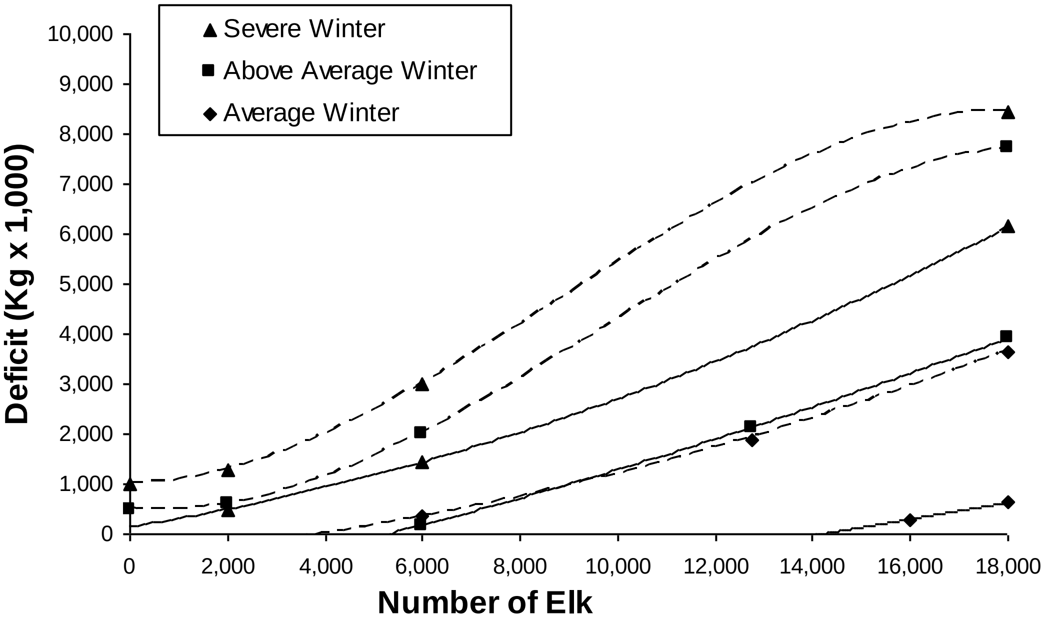

Figure 27. Deficit results for the Greater Teton Ecosystem with one-half of the forage available in vegetation coded "shrub riparian/willow" on the NER. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

Model Results for Alternative #4

Alternative #4 assumptions: 1) 350 bison, 2) cultivated fields on the NER are center-pivot irrigated, and 3) willow on the NER is all fenced off or half-fenced off.

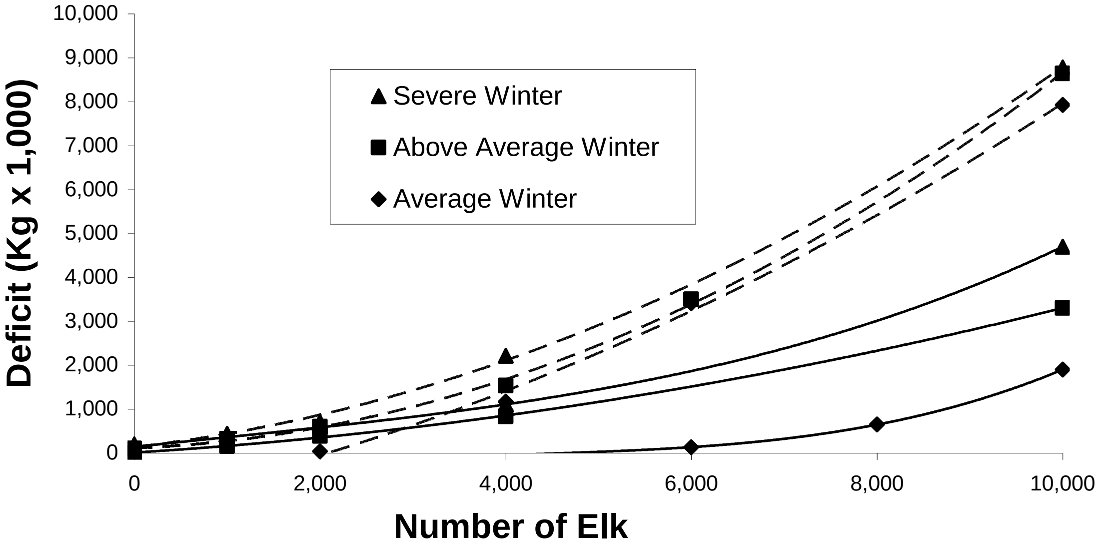

Figure 28. Deficit results for the NER with no forage available in vegetation coded "shrub riparian/willow". The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

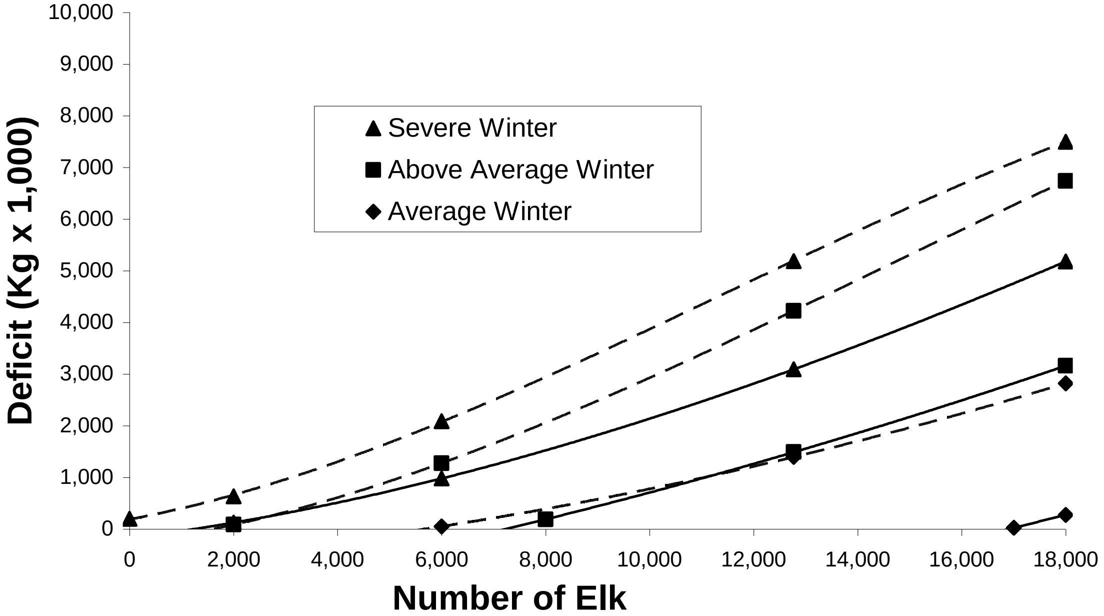

Figure 29. Deficit results for the Greater Teton Ecosystem with no forage available in vegetation coded "shrub riparian/willow" on the NER. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

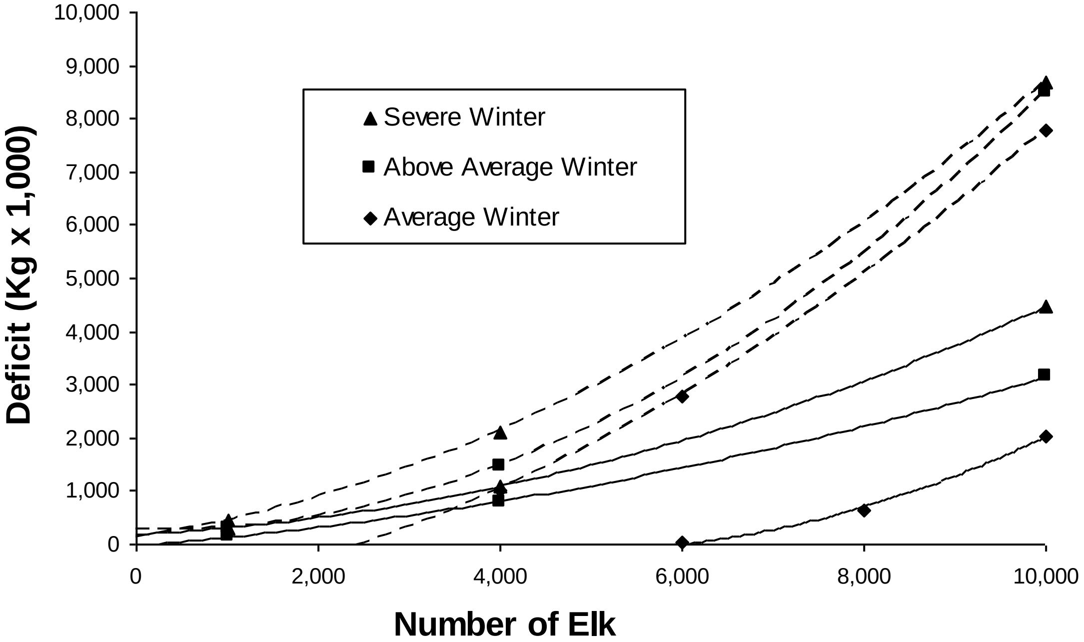

Figure 30. Deficit results for the NER with one-half of the forage available in vegetation coded "shrub riparian/willow". The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

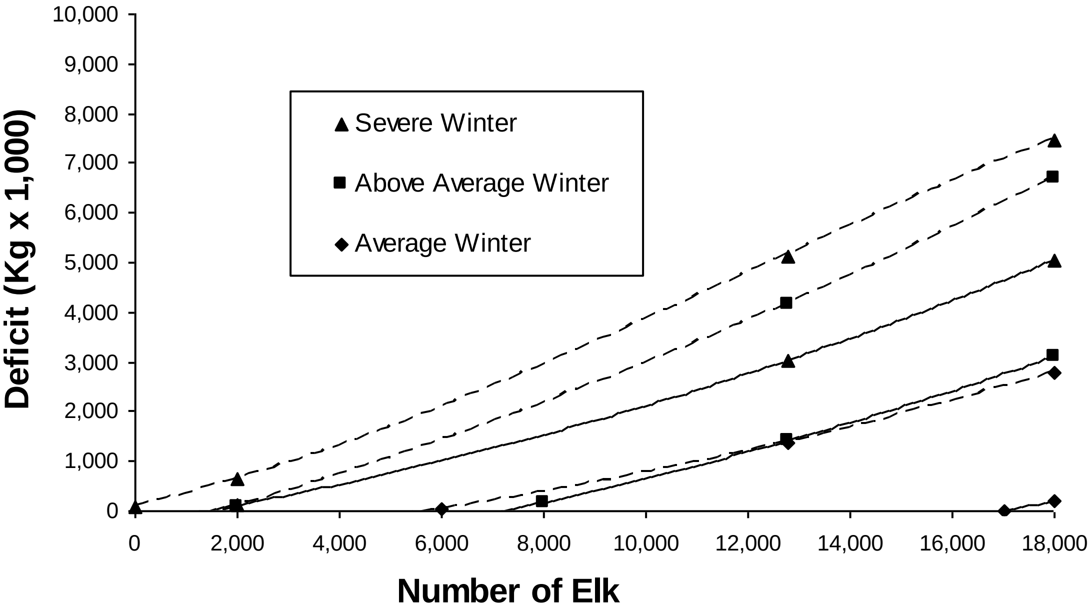

Figure 31. Deficit results for the Greater Teton Ecosystem with one-half of the forage available in vegetation coded "shrub riparian/willow" on the NER. The solid lines represent mean precipitation conditions, and the dashed lines represent drought precipitation conditions.

Discussion for Alternatives #2 - #4

The EIS Alternatives attempt consider effects of manipuating three variables: bison numbers, willow availability on the NER, and irrigation of the NER's cultivated fields. The net effect on forage deficits of these three variables will be the following:

1. increasing bison numbers will increase deficits
2. fencing off willow on the NER will increase deficits
3. irrigating the cultivated fields on the NER will decrease deficits -- center-pivot more so, flood irrigation less so.

Because the vegetation manipulations (willow, irrigation) occur on the lower portion of the NER, the effects will be less pronounced when the model is run on the Greater Teton Ecosystem than the NER. Additionally, because above average and severe winters have some weeks where snow blankets the landscape, the effects of vegetation manipulations are less pronounced than in average winters.

Alternative #2 tries to mimic "natural vegetation conditions" by allowing willow use and not irrigating the cultivated fields. This alternative also tries to manipulate bison numbers, keeping them at either 250 or 500. The net effect of "natural conditions" is slightly higher overall deficits than Alternative #1, and slightly fewer elk before deficits occur. In the average winter with average precipitation and 500 bison, deficits begin at 5,000 elk in Alternative #1 but begin at 4,500 for Alternative #2. If bison numbers are kept at 250, deficits begin at 5,700 elk for Alternative #2.

Alternative #3 lets bison numbers increase naturally to 1,000, and tries to fence off half or all of the willow stands on the NER. This Alternative restricts forage for elk more than any other Alternative because both increased bison numbers and willow fencing cause higher deficits. In an average winter with average precipitation and no willow availability, deficits begin at 3,300 elk. With one-half willow availability, deficits begin at 3,500 elk.

Alternative #4 attempts to hold bison numbers to 350 while center-pivot irrigating the cultivated fields and fencing off willows. Taken in pieces, lower bison numbers (350) will decrease deficits, center-pivot irrigation will decrease deficits, and willow fencing will increase deficits. The net effect of these three manipulations is slightly lower deficits than Alternative #1 which allows slightly more elk to find forage before deficits occur. In an average winter with average precipitation conditions and 350 bison, deficits begin at 5,500 elk when all the willow is fenced off and 6,000 elk when one-half of the willow is fenced off.

In total, the manipulations in the three EIS Alternatives have fairly mild effects on forage deficits and elk numbers. Only Alternative #3, which allows 1,000 bison and fences willow has a significant restricting effect. The net effects of Alternatives #2 and #4 vary little from status quo management. Both the willow area and the irrigated fields on the NER comprise roughly 1,000 acres, and are relatively minor portions of the Greater Teton Ecosystem. If managers want to have a significant impact on the deficits for the entire Jackson elk herd, vegetation manipulations will have to occur on a much larger scale. And, as stated earlier, because snow blankets the landscape in some weeks of above average and severe winters, vegetation manipulations have significantly less effect than in average winters.

Part II.
CENTURY Ecosystem Modeling

Results from simulations using the Forage Accounting Model in Part I of this report suggest that significant areas of the range will experience forage utilization exceeding 50% . High levels of use will occur for virtually all population levels of elk during all winters. This heavy utilization on the winter range is intensified by the existence of the wildlife fence that inhibits natural migration to lower snow-free elevations. Additionally, field measurements (Steele et al. 1999) also depict heavy utilizations throughout the winter range in the lower portion of the NER and the lower elevations of the Gros Ventre Valley. In this section, we report results from simulation modeling using CENTURY to portray biogeochemical changes in vegetation and soil resulting from grazing by elk and bison in the Jackson Valley. This modeling effort is based on estimated inputs of soil and vegetation chemistry because field data were not yet available. Current and ongoing field sampling work by F. Singer on nitrogen pools and vegetation will later be used to corroborate these preliminary findings. The central question we address is whether or not high levels of grazing will harm long term productivity of vegetation communities.

The CENTURY Model

The CENTURY ecosystem model (Metherell et al. 1993) simulates exchanges of carbon (C) and nitrogen (N) among the atmosphere, soil, and vegetation. Required inputs used to drive the model include monthly maximum/minimum temperature and precipitation data, soil properties, vegetation type, and current and historical land use. Disturbances and management practices such as grazing, fire, cultivation, and fertilizer additions can be simulated. CENTURY includes submodels for plant productivity, decomposition of dead plant material and soil organic matter (SOM), and soil water and temperature dynamics. Flows of C and N are controlled by the amount of C in the various pools (e.g. SOM, plant biomass), the N and lignin concentrations of the pools, abiotic temperature/soil water factors, and soil physical properties related to texture. SOM is divided into three pools based on decomposition rates (Parton et al. 1993, 1994). Decomposition of SOM and external nutrient additions supply the nutrient pool that is available for plant growth. Plant growth is controlled by a plant-specific maximum growth parameter, nutrient availability, and 0-1 multipliers that reflect shading, water, and temperature stress. Net Primary Productivity (NPP) is allocated among leafy, woody, and root compartments as a function of plant type, season, soil water content, and nutrient availability.

CENTURY has been used to successfully simulate soil C and NPP levels in various natural and managed systems including grasslands (Parton et al. 1993) and agricultural systems (Parton and Rasmussen 1994). For this project, the grazing subroutine was used to model the effect of migrating elk on the native, otherwise-unimpacted grass and shrublands on the NER and the Gros Ventre Valley. Although dozens of output variables are available, this modeling effort focused on soil C, soil N, and annual NPP because these variables are of most interest to range managers. A flowchart representing the CENTURY model is in Figure 1.

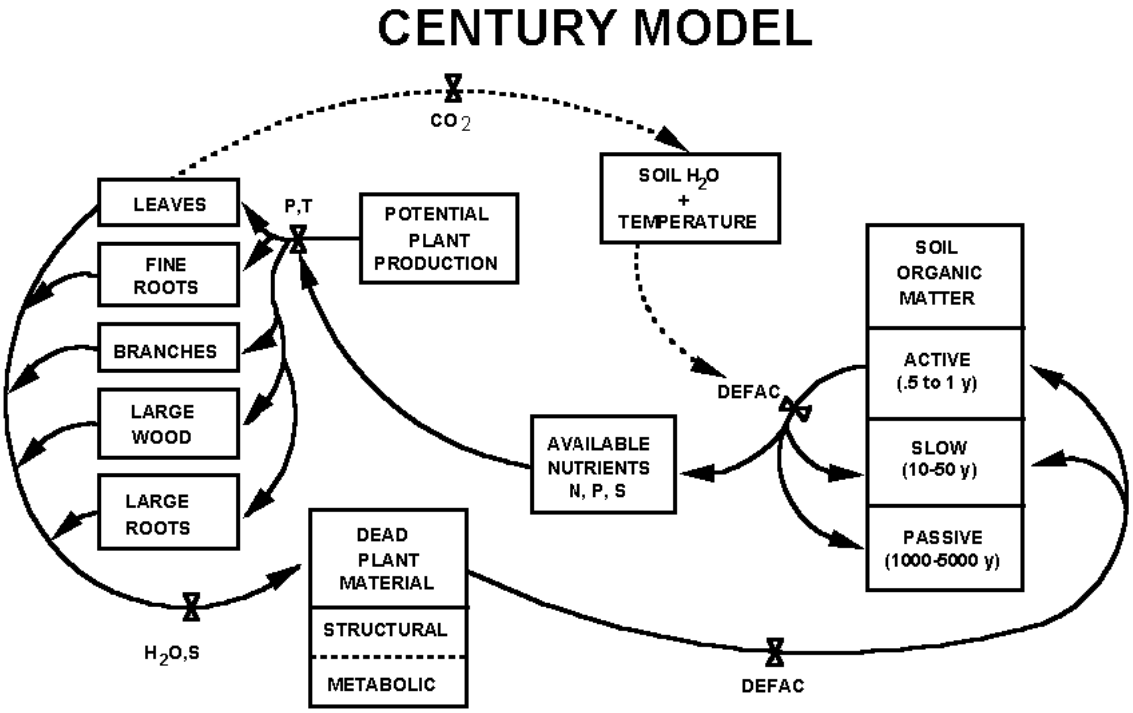

Figure 1. Flowchart of CENTURY Model

Model Input Parameters

Vegetation Types

Two vegetation types were simulated -- wet meadow and sagebrush. We assumed wet meadow is 100% herbaceous with annual production values of ~200 gC/m^2; sagebrush is a 50/50 herbacesou/sagebrush mix with annual production values ~120 gC/m^2. These production values were also used in the Forage Accounting Model, and were derived from field measurements (Zeigenfuss et al. 2001).

These vegetation types were chosen for two reasons. First, they are the same vegetation types being sampled by F. Singer for N processes and N pools for the future nitrogen/CENTURY modeling work in the Jackson Valley. Field measurements will be taken in these types in 2001 and 2002. Second, they also correspond with the major vegetation types that receive significant offtake in the Forage Accounting Model, and comprise much of the NER and the winter range in the Gros Ventre. Figure 2 below, predicted by the Forage Accounting Model, depicts the areas in an average winter with average precipitation and 500 bison where utilizations were 50% or greater.

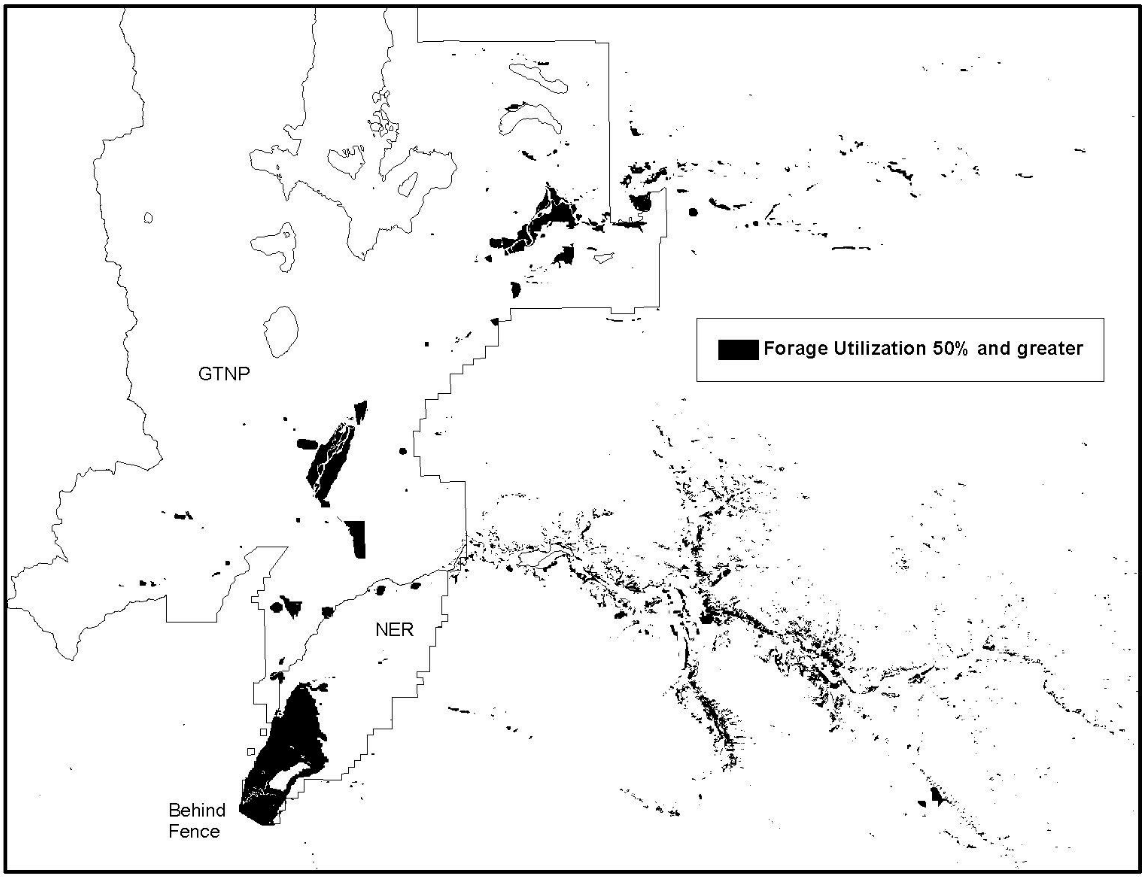

Figure 2. Areas in an average winter with average precipitation and 500 bision where utilization was 50% or greater.

Weather

Weather is a primary driver of the CENTURY model. Monthly weather data were obtained from the permanent weather station at Moose, Wyoming. Although stations at Jackson and Moran were also available, the station at Moose provided temperature and precipitation measurements midway between the poles of Jackson and Moran, and thus provided a reasonable compromise that could be used for the entire low-lying winter range in the Valley.

Other Input Parameters

Other primary input parameters include soil type and texture, C/N ratios, life span and other parameters for the vegetation types, and annual N inputs from wet and dry deposition. Soil and vegetation parameters were based on values used in CENTURY simulations of a similar system in Rocky Mountain National Park (Schoenecker et al. 2002). Annual N inputs were tuned so that simulated NPP values agreed with observed NPP for the sagebrush and meadow communities. Required N inputs were higher for the meadow than the sagebrush/grass system. This is reasonable because low-lying meadows are depositional zones and they receive nutrient inputs from surface runoff and other sources.

Modeling Assumptions

Three modeling assumptions guided this process. The wildlife fence near Jackson was built in the 1950s to keep elk from feeding on farmland during the winter. The fence partially obstructs natural migration paths down the Valley especially in severe winters when elk usually migrated to lower elevations down the Snake River through and beyond the town of Jackson. Thus, for the simplified purposes of modeling, we first assumed that no grazing occurred on the winter range prior to the construction of the fence. Using Annual Net Primary Production values measured from field data, we let the model reach equilibrium over a 2,900-year time-span during this no-grazing period. This assumption is reasonable because the production values were derived from elk-free enclosures on the winter range and therefore mimic grazed-free pre-fence production on native vegetation types.

The second assumption is that after the wildlife fence is built, elk are artificially concentrated on the winter range and therefore graze at unnatural levels on the grass and shrubland. This is the same assumption that guides grazing in the Forage Accounting Model. We modeled two grazing intensities, 50% and 80%, of standing dead grass and shrub. All grazing occurs during the months of January through April, and, because the forage is dead and the ground frozen, this causes no negative effect on the next year's production.

Third, standing dead grass is poor quality forage for elk and has significantly less nitrogen content than summer grasses. One of the driving input parameters for CENTURY in a grazed system is the ratio of nitrogen excreted by the animal to nitrogen consumed. When elk consume standing dead forage, this ratio typically exceeds 1.0. This occurs because the endogenous nitrogen lost from the animal in urine and feces exceeds the nitrogen consumed in forage. Hobbs (1996) and Mould and Robbins (1981) have calculated nitrogen levels in elk excrement in relation to forage quality. These calculations yielded 1.09 gN/day of output-to-intake for poor-quality, standing-dead forage when elk have a stable bodyweight. Additionally, when elk are eating poor quality forage in the depth of winter, they often lose weight. Thus, we also modeled a scenario where elk lost 15% of their body weight over the four-month grazing period. Losing weight causes yet more nitrogen from the animal's lean body mass to pass through the urine therefore increasing the nitrogen output/intake ratio (Hobbs 1989, D.M. Swift pers. comm.). When elk lose weight, we used a ratio of 1.25 gN/day of output-to-intake.

Results

In the wet meadow graphs (Figure 3), the first 50 years of the model depict the pre-grazing equilibrium scenario. Beginning in year 51, when the fence was built, we simulated two levels of grazing intensity, 50% and 80%. Both grazing levels accelerate nutrient cycling and cause increases in soil carbon and net annual production. The magnitude of this accelerating effect is proportionate to grazing intensity, with greater effects occurring at 80% grazing intensity. When elk are losing weight, higher N inputs accelerate the system to an even greater extent and increased plant production leads to higher soil carbon levels.

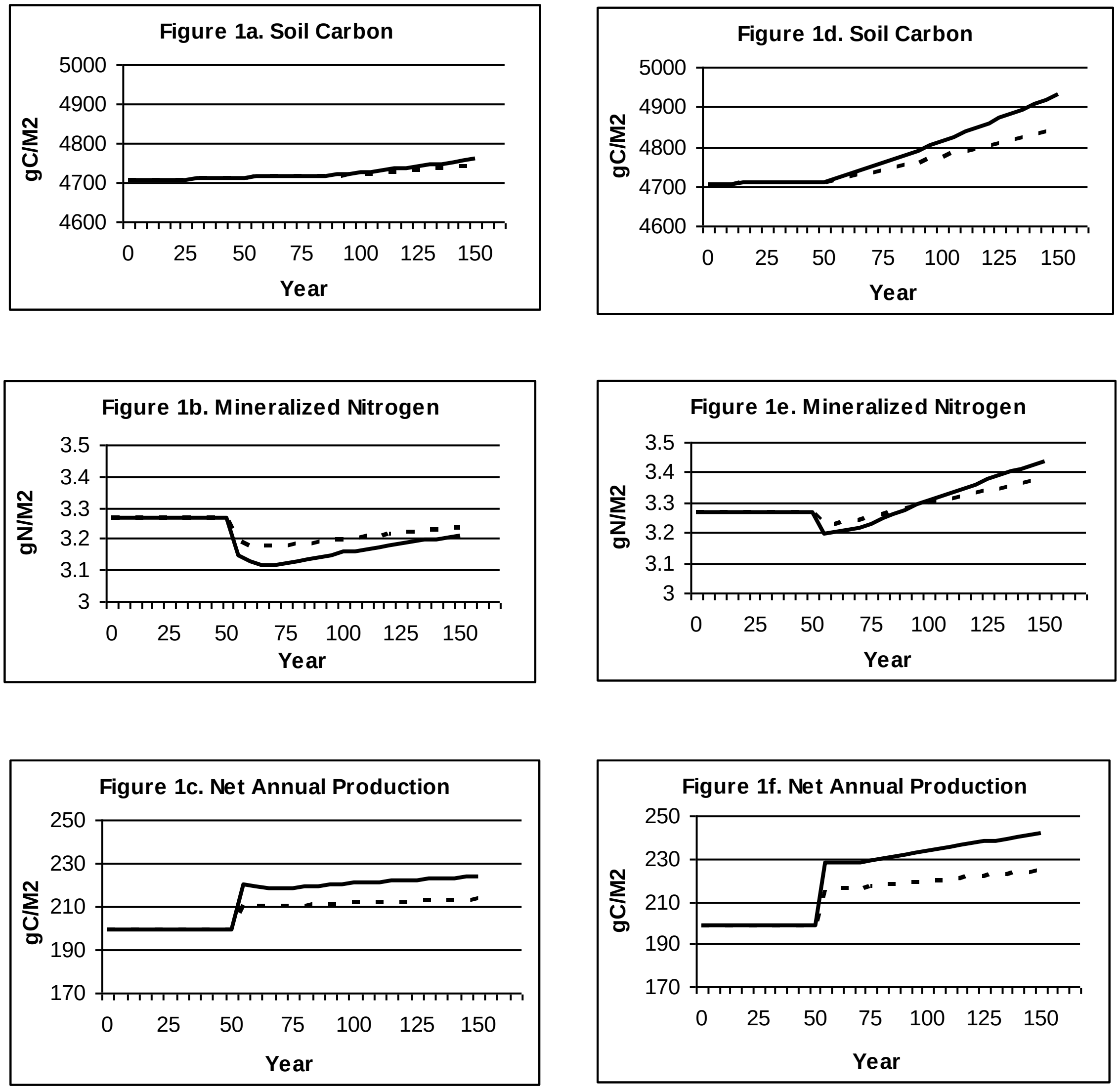

Figure 1a. Soil Carbon

Figure 1d. Soil Carbon

Figure 1b. Mineralized Nitrogen

Figure 1e. Mineralized Nitrogen

Figure 1c. Net Annual Production

Figure 1f. Net Annual Production

Figure 3. Model Results for Wet Meadow at two grazing levels. The solid black line depicts 80% removal of forage and the dotted line depicts 50% removal. The three graphs on the left depict the “Elk not losing weight” scenario; the three graphs on the right “Elk losing weight” scenario.

Similarly, in the sagebrush graphs (Figure 4), the first 50 years of the model depict the pre-grazing equilibrium scenario. Beginning in year 51, when the fence was built, we simulated two levels of grazing intensity, 50% and 80%. When elk are not losing weight (Figure 4 – left), soil carbon and mineralized nitrogen remain stable or slowly decline. Net annual production initially jumps to a higher level and then stabilizes over the 100-year model run. The higher level of grazing causes slightly increased production; the lower level causes stabilized production. When elk are losing weight (Figure 4 – right), all values increase. Net annual production increases faster with the higher grazing level and when elk are losing weight. Both of these can be explained by N inputs. Because the dead forage is of such poor quality the animals excrete more N than they extract from the system and this shifts carbon-nitrogen ratios in soil toward levels favoring N-mineralization. As grazing intensity increases, net N inputs to the system also increase, and when elk are losing weight the ratio of N outputs to inputs is even higher. Higher N inputs lead to enhanced mineralization, which release more N from soil organic matter. This feedback causes increased plant growth and stable or increasing soil C levels.

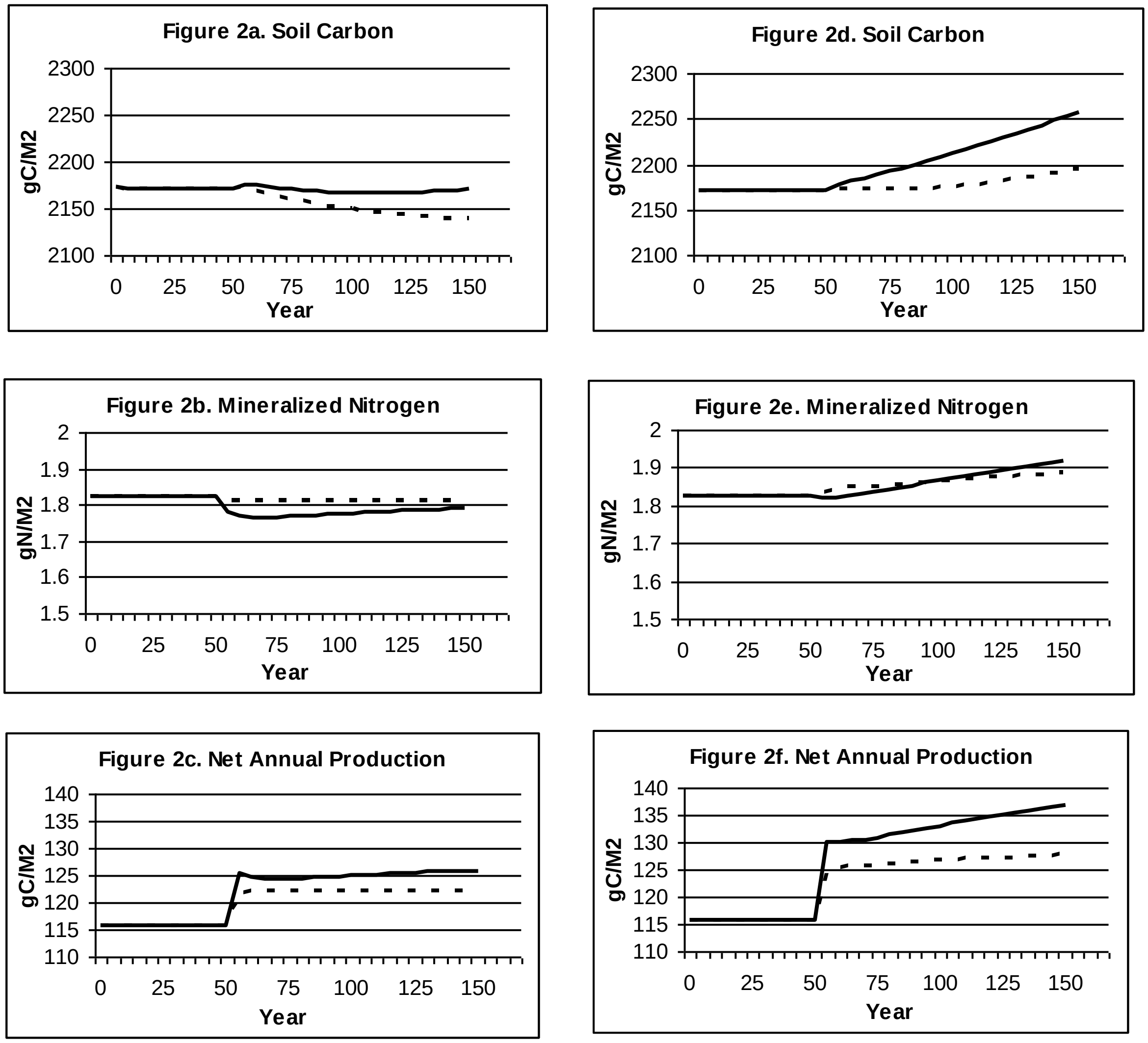

Figure 4. Model Results for Sagebrush at two grazing levels. The solid black line depicts 80% removal of forage and the dotted line depicts 50% removal. Figure 2a – 2c depict the “Elk not losing weight” scenario. Figure 1d – 1f depict the “Elk losing weight” scenario.

Overall, all twelve charts depict a similar scenario. Because elk are consuming standing dead forage in the depth of winter, there is no negative effect on plant production. Further, because elk cause accelerated nutrient cycling, and because elk are returning more nitrogen to the soil than they consume, higher grazing levels will cause higher future production levels. As long as elk are concentrated at high densities on the winter range, the CENTURY model will predict positive feedbacks on production due to higher net N inputs related to grazing. The feedback is exacerbated due to low N volatilization because of weather conditions. We presume that cold weather and snow cover keep N from volatizing into the atmosphere during winter.

These CENTURY results suggest that heavy winter-season grazing in this system, as predicted by the Forage Accounting Model, is sustainable and that soil C and nutrient levels are not significantly depleted and may increase. Nitrogen ‘hotspots’ and higher production will occur corresponding to animal density. If elk stay on the winter range longer with low-grade forage resulting in weight loss, increased nitrogen hotspots and increased future production will result. Figure 1 could also been seen as a ‘nitrogen deposition map’ wherein animals deposit nitrogen gathered throughout the entire summer range onto this limited winter area. Further fieldwork by F. Singer, will help corroborate these findings.

Part III.
The Over-Winter Mortality Model

Introduction

Forage deficits, predicted by the Forage Accounting Model (described in Part I), will likely cause elevated mortality in over-wintering elk populations. We adapted the energy balance model of Hobbs (1989) to estimate starvation mortality by simulating energy intake and expenditure by elk in four age/sex classes (calves, yearling males, adult females, bulls) during winter. The predictions of mortality provided by this model are perhaps more easily interpreted than the predictions of forage deficits and overuse provided by the Forage Accounting Model. However, while these interpretations may be easier to understand, they are also subject to a far greater potential for error. This is simply because the Over-Winter Mortality Model has approximately 10 times as many parameters as the Forage Accounting Model, and all of these parameters are estimated with some uncertainty. Therefore, we suggest that quantitative results of the energy balance model should be viewed with caution. However, we are confident that the qualitative trends we have observed are reasonable.

Methods

Elk populations were allocated to map cells based on snow water equivalents (SWE) under the assumption that elk use the areas of the landscape with shallow SWE in preference to areas with deep SWE, and that they will not use areas with > 6" SWE. So, during each week of the winter, we distributed the total population to map cells with SWE < 6" in order of increasing SWE. The number of animals assigned to a cell was determined by the available biomass of forage within that cell, an output variable in the Forage Accounting Model. We calculated the weekly requirements of individuals and assigned no more animals than could be supported for 1 week by the available biomass. We assumed that a group of elk or sub-herd in the cells of a SWE category (0, 1, 2, … , inch) had the same age/sex composition as the entire herd (proportion of calves: 0.15; yearling males: 0.05; bulls: 0.15; cows: 0.65). If a SWE-depth category of cells could support < 5 elk, then only bulls were assigned to these cells. We calculated daily intake based on the average body mass of sex and age classes and their proportions in the population assuming the body mass of a calf (age = 6 months) was 200 pounds, yearling 350 pounds, bull 675 pounds, and cow 500 pounds.

Foods were categorized into two categories, herbaceous and shrubs. We assumed that when SWE > 30 cm, shrubs comprised 100% of elk diet. If the SWE depth was in the range of 20-30 cm, the proportion of herbs in the diet increased in direct proportion to decreasing SWE. When SWE < 20 cm, the diet consisted of 100% herbs. Available foods of the cells of each SWE-depth category were updated daily by removing the amount of biomass consumed by elk.

The percentage of each age class that dies was based on assumed average fatness and the standard deviation in fat reserves at the beginning of the winter. We assumed that 67% of pre-winter energy reserves came from fat and 33% from lean body and that the size of these reserves was a normally distributed random variable. Based on that assumption, we used the standard normal probability density function to calculate the proportion of the population that had energy reserves less than the magnitude of the energy deficits incurred during winter. We assumed that this was the proportion of each age class that starves (Hobbs 1989).

We ran simulations with initial conditions for populations set at 6,000, 12,771 and 18,000 animals for an average winter (1996), above average winter (1982), and severe winter (1997).

Results

Simulated mortality of calves ranged from a low of 4% during an average winter at a total population size of 6,000 to a high of 42% during a severe winter and a population of 18,000 (Figure 1 - 3). Increasing population density was associated with roughly proportionate increases in estimated mortality. Starvation mortality for adult cows was predicted to be 1% for a population of 6,000 animals in an average winter rising to a high of 25% for a population of 18,000 during a severe winter.

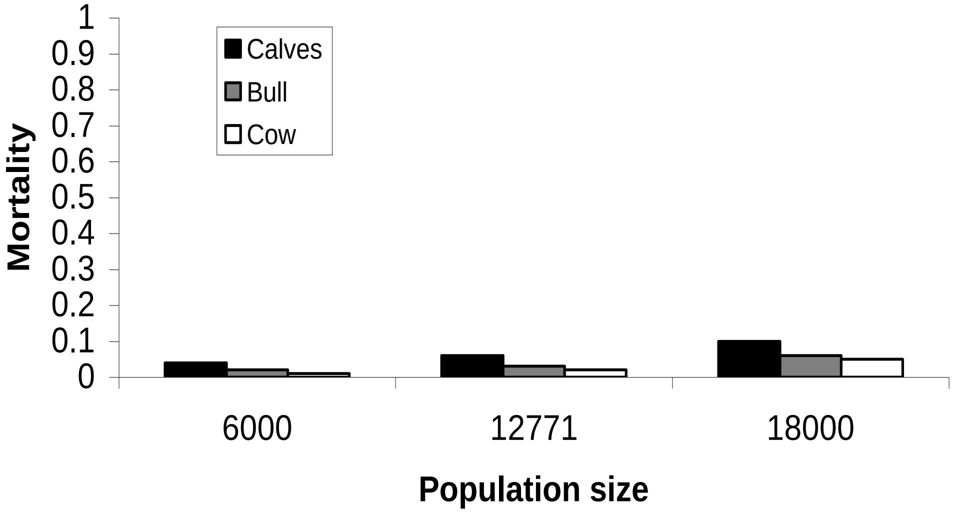

Figure 1. Simulations of elk winter mortalities for the Jackson Elk Herd under different densities in average winter (1996).

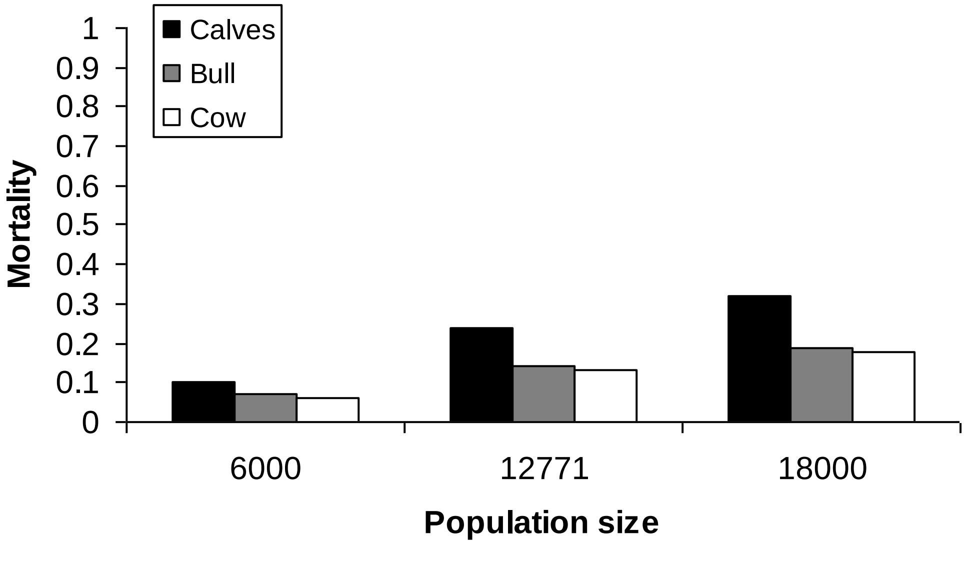

Figure 2. Simulations of elk winter mortalities for the Jackson Elk Herd under different densities in above average winter (1982).

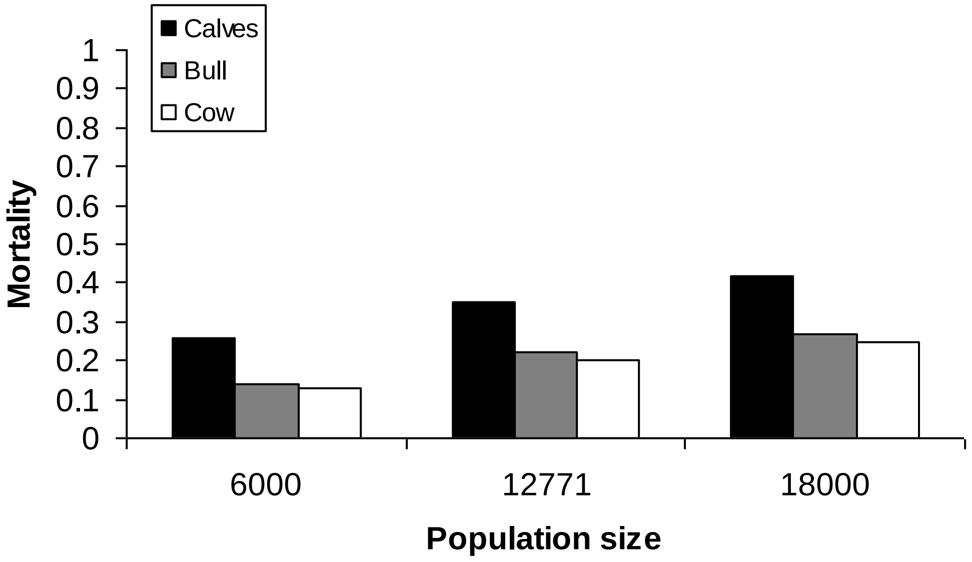

Figure 3. Simulations of elk winter mortalities for the Jackson Elk Herd under different densities in severe winter (1997).

Conclusions

The main implications of these three overlapping models are:

1. Forage utilization rates of 50% and greater will occur on the winter range at all elk population levels and during all winter severities. The area of winter range used in excess of 50% will increase with the elk population and winter severity. However, although high utilization rates will occur on the winter range, they may not negatively effect, and may even enhance, future soil fertility and plant production.

2. In average SWE winters with average pre-winter precipitation and 500 bison, roughly 16,000 elk can find forage on the Greater Teton Ecosystem without incurring forage deficits and roughly 5,000 elk can find forage on the NER without incurring deficits.

3. Winter snow severity has a deleterious effect on forage availability and causes critical imbalances in forage supply/demand at most elk population levels.

4. Drought reduces forage production to 45% of the mean and increases deficits in all winter conditions and with all elk populations levels. When drought during the growing season precedes deep-snow winters, forage deficits are extreme.

5. Increasing the number of bison has a mild effect on forage deficits on the Greater Teton Ecosystem during average winters with average precipitation conditions, but has a more significant effect when climatic conditions worsen. On the NER, increasing bison numbers will greatly exacerbate deficits and the ability of elk to find adequate forage.

6. Cattle grazing has a negligible effect on forage deficits because it does not occur on areas where forage is available to native ungulates during winter.

7. Supplemental feeding overcompensates for the forage unavailable south of the wildlife fence. Historic elk populations either: (1) were smaller than current ones, and/or (2) may have suffered high levels of mortality during severe winters, and/or (3) more likely have used lower elevation ranges south of Jackson and larger areas of the Gros Ventre.

8. Starvation of adult animals is expected to occur at relatively low levels (about 5%) at all levels of population and winter severity, but may increase to as high as 30% during severe winters and with high population levels (18,000).

9. Only EIS Alternative #3 has the significant effect of restricting forage availability for elk and increasing forage deficits. Alternatives #2 and #4 have only mild effects. The EIS Alternatives attempt to manipulate three variables: bison numbers, willow availability on the NER, and irrigation of the NER's cultivated fields. The net effect on forage deficits of these three variables will be the following:

   a. increasing bison numbers will increase deficits
   b. fencing off willow on the NER will increase deficits
   c. irrigating the cultivated fields on the NER will decrease deficits -- center-pivot more so, flood irrigation less so.

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Appendix A: Vegetation Production Methods

Data on annual production for each vegetation type were obtained from studies conducted by Biological Resources Division (BRD)--USGS, National Elk Refuge (NER)--USFWS, and Bridger-Teton National Forest (BTNF)--USFS. Each data set was collected in a different manner and so it was necessary to standardize the data so that they could be combined to create the largest data set possible for estimating average production values.

The BTNF data were collected from 1994-1999. Sample points were randomly generated in areas of highest priority for forest management activities. As a result, less information was available on vegetation types that do not encompass areas of high management priority. Data on plant production was visually estimated in weight classes. For the purpose of estimating average production, the midpoint of the class was assigned to the sample point (Appendix C: Table 2).

Data on dominant and codominant tree, shrub, and herbaceous species were assessed to determine the appropriate USU vegetation categories for each sample. Because no data were available on forest canopy closure at the sample points, all points in forested types of a species (or species grouping) were combined. Total production was calculated by summing the midpoints for shrub, grass, and forb production.

Data from the NER were collected from 1987-1999, however, data for the entire refuge exists in electronic format for 1999 only. The remainder of the 1987-1999 data is from the south end of the refuge, and as a result, some vegetation types which only occur in the north end of the refuge are only represented in 1999. Production was estimated using the SCS double sampling method, whereby ocular estimates are made for all points on a transect in a particular vegetation type, and a subsample of these points are clipped and weighed and used to calibrate the points which had only ocular estimation.

Plant productivity estimates for the BRD study were collected from 1996-1998 and were obtained by clipping, drying, and weighing vegetation in several 0.25 m^2 quadrats at several sites for each vegetation type.

Mean production values were calculated for each vegetation category in each of the data sets. Vegetation was grouped in broad categories based on dominant tree, shrub, or herb species and tested for differences between all the individual categories within these broad groups using Fisher's least significant difference test for multiple comparison of means. Based on the results of these tests, 15 new vegetation categories were developed. The final mean production values for the new vegetation categories were calculated using all data from the three data sets. No data existed in the available data sets for three of the new categories: alpine herbaceous, alpine shrub, and disturbed/developed. Production values for the alpine categories were approximated based on work done by Marilyn Walker at the Niwot Ridge Long Term Experimental Range near Nederland, Colorado. These data were found on the Niwot LTER web site. Values for disturbed/developed areas, where irrigated and fertilized lawns are maintained, were expected to be similar to values for sub-irrigated bluegrass found in the NER and BRD data. The values estimated using these data were similar to those measured in disturbed sites in the town of Estes Park, Colorado in another study (Singer et al. 2002) and such values were therefore considered adequate.

Estimating production in wet and dry years was approached two ways. First, using annual precipitation and 30-year average precipitation values available on the web from the University of

Nebraska's High Plains Climate Center, several years with greater than average (1996 and 1997) and lower than average (2001, 1994, 1992, 1988) precipitation at the Jackson, Moose, and Moran weather stations were chosen. Average production values were calculated for the wet years and dry years for each vegetation category and each data set separately. Because reliable data for wet, dry, and average years were not available for all vegetation types, the percentage of mean annual production for those types that were best represented were calculated for each data set for both wet and dry years, and then these best data were averaged to get a mean percentage of production to be applied across all vegetation types.

Dry year production ranged from .45 -.91 of annual production across the data sets with a mean of 0.85. Wet year production ranged from 1.29-1.8 of annual production across all data sets with a mean of 1.5. We chose to use 1.5 as the wet year production and 0.45 as the dry year. 0.45 was chosen because managers wanted a severe draught scenario based on recent 2001 precipitation.

Managers raised a question about the spatial heterogeneity of production due to varying rainfall over the study area. For example, sagebrush on the NER may produce differently than sagebrush in the Gros Ventre. We attempted to create a spatially explicit production map based on actual production measurements across the study area. However, these estimations did not yield significant spatial differences in production for each vegetation type. While we recognize that rainfall may vary across this area, and that production may vary with it, field data could not support these distinctions.

Appendix B: Snow Model Methods

The model is based on an algorithm to spatially interpolate point data, while correcting for effects of elevation. This algorithm was first developed by Michael Coughenour as part of a spatially explicit ecosystem model called SAVANNA (Coughenour 1992, 1993). The same algorithm was used in a Landscape Carrying Capacity Model for elk on Yellowstone's northern elk winter range (Coughenour 1994, Coughenour and Singer 1996). The first application of the model to Yellowstone was at a research conference held in Yellowstone in 1991 (Coughenour 1994). In this application, GRASS GIS maps for elevation and vegetation were read into a model to calculate snow depth maps, available forage for elk, and elk carrying capacity on a biweekly basis throughout the winter. The model produced output files that were read into the GRASS GIS, to produce maps of snow depth and elk carrying capacity. These output maps were presented at the 1991 conference.

At about the same time, Phil Farnes was conducting studies of snow distributions on the Yellowstone northern elk winter range (Farnes and Romme 1993). He quantified the ways that slope, aspect, and tree cover affect snow pack, as compared to measurements made on a standard, level, treeless sample site. He also developed ways to integrate data from numerous snow water sample sites into a unified data base, and ways to use snow water equivalent to calculate an index of winter severity that combines stress effects of cold temperature and heavy snow on elk (Farnes et al. 1999).

The idea of combining the Coughenour model with the Farnes data into a stand-alone data model was the outcome of initial research on bison and elk carrying capacity by the two researchers in Grand Teton National Park (GTNP). The idea for that project was conceived by Robert Schiller and Francis Singer. Coughenour conducted preliminary SAVANNA modeling studies and Farnes collected snow data in GTNP. To create the stand-alone model, Coughenour combined his earlier elevation-based model with the slope/aspect/tree cover relationships of Farnes, in order to convert the snow data assembled by Farnes into maps of snow water equivalents in GTNP. The snow data model was delivered to GTNP by Coughenour and Farnes in 1999, at the same time Farnes delivered his unique data set (Farnes et al. 1999). Subsequently, a new phase of GTNP carrying capacity research was initiated by N. T. Hobbs, F. Singer, G. Wockner, and L. Ziegenfuss.

In 2000, Gary Wockner, Tom Hobbs, and Francis Singer (CSU) obtained the model from Coughenour for this new phase of the GTNP project (Hobbs et al. 2001). Working with Farnes and Coughenour, Wockner obtained data to run it, worked through several software bugs, tested it, and then used it in the forage accounting model for the Jackson elk herd.

The snow model is driven by three primary sources of data, a digital elevation model, data on vegetation distribution, and point data on snow distribution. Using the DEM and the snow data, an initial grid is created using interpolation and regression. Then, this grid is readjusted for the effect of slope, aspect, and vegetation cover. Using slope and aspect, the more the cell tilts toward the sun, the more it is melted off; conversely, the more it is tilted away from the sun, the more snow accumulates. Using the vegetation data, the grid is adjusted for less snow accumulation under conifers. The bigger the trees and the denser the stand, the less snow accumulation.

Digital Elevation Model

A digital elevation model (DEM) was obtained from NREL researchers working on a similar project in the Greater Yellowstone Area. The DEM is at 30-meter accuracy and covers the entire study area. In Arcview, the DEM was clipped to the study area and exported as an ASCII file for use in the snow model. The DEM was then converted into a slope grid using Arcview's "Spatial.Slope" function, and converted into an aspect grid using Arcview's "Spatial.Aspect" function. Arcview's Spatial.Aspect command assigns the value "-1" to flat areas. Because the snow model will not read "-1"s, these areas were reassigned the value "300" which results in no multiplier being used in the snow model. These two grids were then converted into integer grids to decrease file size and then exported in ASCII format for use in the snow model

Vegetation Data
The snow model uses the merged vegetation grids from Utah State University, Grand Teton National Park, and the National Elk Refuge. Each of the three grids had relevant codes to use in the snow model. The Utah State coverage had a code titled "canopy percent"; the GTNP coverage had a code for "forest successional stage"; and the NER coverage only had one applicable forested area. These codes were converted into codes readable by the snow model using a crosswalk table (Appendix C: Table 5). Because dense conifer stands will result in less snow on the ground under those stands, the following tree types cause the snow model to create an adjustment: Lodgepole Pine, Subalpine Pine, Douglas Fir, Englemann Spruce. This adjustment is a multiplier which decreases SWE based on the size of the trees and the density of the stand.

Snow Data
The model interpolates the snow station data provided by Farnes. Several types of data are available in the Jackson Valley including snow courses, SNOTEL sites, and climatological stations. In addition, Farnes collected additional monthly data at over 75 stations beginning in water-year 1996. After the large study area was chosen, snow stations within that area were identified. The snow model incorporates data from 6 long-term stations which have daily data beginning at least from 1980 and uses monthly data (Feb, Mar, Apr) from 56 additional stations primarily in Jackson Valley. Snow sampling locations are shown in Figure 1 (Part I.). The snow model also requires a file containing UTM location and elevation of each station. This data was taken from the DEM by overlaying the snow station locations on the DEM and assigning the elevation attribute of the DEM to each station.

The 6 long-term stations ranged from the highest, Togwotee Pass--9580 feet, to the lowest, Jackson--6230 feet. The other four stations were: Moose--6468 feet, Moran--6798 feet, Base Camp--7030 feet, and Phillips Bench--8200 feet. The 56 additional stations contained monthly data collected February, March, and April 1st in 1996, 1997, and 1998. The names, locations, and elevations of all stations are listed in Appendix C: Table 6.

Data at the 6 daily sites existed from water-year (W-Y) 1980 to present. Because W-Y 1981 had one of the lowest SWEs on record and W-Y 1997 had one of the highest (Farnes et al. 1999), a 20-year (1980-1999) stretch of time provided ample variability for useful modeling. At the time of this report, 1999 was the last year of data that was processed by Farnes/Heydon and available for analysis.

The current modeling effort steps through the winter from the onset of snow to its end--roughly November 1st to July 1st. Thus, year-round daily data estimates for all 19 years needed to be created for the 56 monthly stations where data was only collected on February, March, and April 1st of 1996-1999. We developed a regression technique to estimate the missing data at the additional sites. Because snow varies due to elevation and location throughout the study area, each of the original daily stations could be used as independent variables in a regression function to predict the missing data at the monthly sites. This process was carried out with these steps:

1. In S-plus a matrix of data was assembled which contained SWE on Feb, Mar, and Apr 1st in 1996, 1997, and 1998 at all 62 locations. These 9x62 data points contain measured SWE at all locations.
2. A correlation matrix was constructed to determine which of the independent daily stations would serve as best predictors for the dependent monthly stations.
3. Using this matrix, and a more subjective analysis of snow patterns and elevations, a table was constructed which divided the 6 daily stations into three groups. Group 1 contained Jackson, Group 2 contained Moose and Moran, Group 3 contained Base Camp, Phillips Bench, and Togwotee Pass. Each monthly station was assigned to one of these three groups. There were roughly three snow patterns in all the data. The first were sites that increased on March 1st and then melted to "0" or near on April 1st. The second were sites that increased on March 1st and decreased on April 1st but not to near "0". The third were sites that increased on March 1st and then increased again on April 1st. The assignment appears in Appendix C: Table 7.
4. A regression equation was developed in S-plus using stepwise linear regression with "0" as the Y-intercept for each of the 56 monthly stations from the independent predictors in each group. This particular method was developed after several attempts at using other regression methods and switches. Forcing the Y-intercept to "0" provided the best fit of the data at the tails of the curves. (The output -- r^2, equations, etc -- is available for review) Additionally, a few of the regressions did not yield a significance with any predictor site. At these supplemental stations, the predictor site with the highest correlation with the supplemental site was 'forced' to provide the regression.
5. These regression equations were pasted into an Excel spreadsheet which contained the daily data for the 6 stations. The daily data was predicted for the 56 monthly stations.
6. The predicted versus observed values were compared for Feb, Mar, and Apr 1st 1996-8, for the 56 dependent variables. Predictions were very good. (This output is also available for review)

After the process was completed Farnes pointed out that Gros Ventre Summit is a long-term daily site rather than a supplemental site. Its daily data was located on a disk from Coughenour and substituted for the predicted data. Because its snow pattern is similar to Togwotee Pass, Phillips Bench, and Base Camp, we saw no need to rerun the regressions which used those sites. Thus there are 7 long-term stations, and 55 supplemental sites used in the final snow model runs.

With the predicted daily data for all 62 stations over the 20-year time span, the snow model allows us to run a simulation of SWE for any day of the snow-year during those 20 years. The primary output of that model is an ASCII file with SWE for each of the cells in the original input grids. Additional output includes a fit-comparison of observed versus predicted SWE at each site, and a file containing r^2, slope, and intercept of the regression function used in the model.

The output ASCII file is imported into Arcview and converted to a grid for visual inspection. The grid is then smoothed twice with a 5x5 filter using Arcview's "FocalStats" function. This smoothing is recommended by Coughenour and causes most of the banding and striping remnant from the DEM to disappear. Adjusting the legends to create any SWE threshold provides the needed visual reference for the migratory switch used in the forage utilization model. A dynamic snow map was also created which visually steps through the winter on a weekly basis in 1997, 1998, and 1999.

Although SWE grids currently begin when depth hits 2 inches, they can be generated anytime snow is present. Grids were modeled four times a month for each snow-water-year on the 1st, 8th, 15th, and 23rd.

Grids were begun when SWE hit 2” at any station and continued until SWE fell below 2”. The earliest occurrence was October 15th; the latest was July 15th. Grids have a 30 meter pixel size and have 1851 rows and 2425 columns for a total of 4,488,675 cells.

The Gros Ventre Correction

At the meetings in Jackson in August 2000, it was agreed that the snow model over estimated SWE in the Gros Ventre Valley because of the snow shadow downwind of the Tetons. Also in the original snow modeling, no input data for the snow model -- which comes from the daily and supplemental sites – exists in the Gros Ventre Valley, the closest being Gros Ventre summit. To test this theory, Farnes’ team collected supplemental SWE data in the Gros Ventre during the winter of 2000. Two dates, February 1st and March 1st , provide enough data points to feed the snow model and check its results. The model was run using all the data for those two dates and the results were discussed with Farnes at a meeting in Fort Collins in October.

While these dates clearly provided a different snow picture than the previous modeling, it was also known that WY2000 was a very light snow year, and thus its effects were questionable. In specific, the predictions at Darwin Ranch were well below the actual measurements. Also, the correction provided a broad and sharp SWE reduction over vast areas in the Gros Ventre. During the meeting with Farnes in October, he described different data not yet analyzed from snow stations at Darwin Ranch and from the feedgrounds in the Gros Ventre. This data comes from four sites – Alkali Feedgrounds, Patrol Cabin Feedgrounds, Fish Creek Feedgrounds, and Darwin Ranch and was collected by the USFS.

This data was sent to Fort Collins in late November and fed into the snow model and was used in two ways. First, we checked the WY2000 snow correction map against these dates, and found that the WY2000 correction was indeed overcorrecting, especially at Darwin Ranch. Because this new data was spread across years 1996-1998, it provided measurements from deeper snow years. Second, we substituted this data into the snow model and made a new correction map. At a meeting in December with Hobbs, Singer, Zeigenfuss, and Wockner, we decided that this newest correction provided the best estimate. Not only did predicted/observed measurements match better at all sites, it also provided the needed correction in the Gros Ventre Valley while leaving the higher elevations with greater snow. The model and the correction were run on several dates, and all provided a reasonable fit.

Figure 1 and Figure 2 (in this appendix) are graphics of the before and after snow model runs on January 14, 1998. These figures clearly depict that the new Gros Ventre data provides a very different SWE picture for the Gros Ventre Valley. The results for several other dates are not shown here but give the same pattern. Additionally, these new data points change the SWE map only a small amount over the southeast quadrant of the study area, whereas previous corrections changed it greatly. Figure 3 is the actual correction map, the details of its creation are below.

Creating the Gros Ventre Correction Map

The correction map was created using these steps:

1. Run the snow model with and without the Gros Ventre data for 12/20/1996 and 01/14/1998. These two dates were picked because they had the highest SWE of the additional dates. Because the larger carrying capacity model is driven by depth-of-winter forage needs in above average snow winters, these highest SWE dates provide the best estimation of severe conditions.
2. Create a ‘multiplier grid’ on each date which reflects the value the “before” grid must by multiplied by to create the “after” corrected grid. For each date, divide the ‘after’

SWE by the 'before' SWE. Thus, if the before SWE grid had a cell that was "7" and after was "4", then a new grid is created with the "multiplier" of "0.5714" in that cell.

3. Average the two "multiplier grids" from the two different dates to best take advantage of the temporal data, thus creating an "average multiplier grid".
4. Define a geographic area around the Gros Ventre Valley in which SWE are measurably different in the "before" and "after" grids and select out the "average multiplier grid" in this area. This area was defined by the Gros Ventre watershed from a GIS coverage.
5. Create a final "correction grid" in which all cells in the broader study area are "1" and the Gros Ventre selection area has the value of the "average multiplier grid".

Thus finally, in the Forage Accounting Model loop, the SWE grid will be multiplied by the "correction grid". The SWE values will be retained in all areas except the Gros Ventre Valley which will be adjusted downward accordingly. This will happen quickly, easily, and unnoticeably in the model. The "correction grid values" are the numbers by which the original SWE grids will be multiplied to adjust downward.

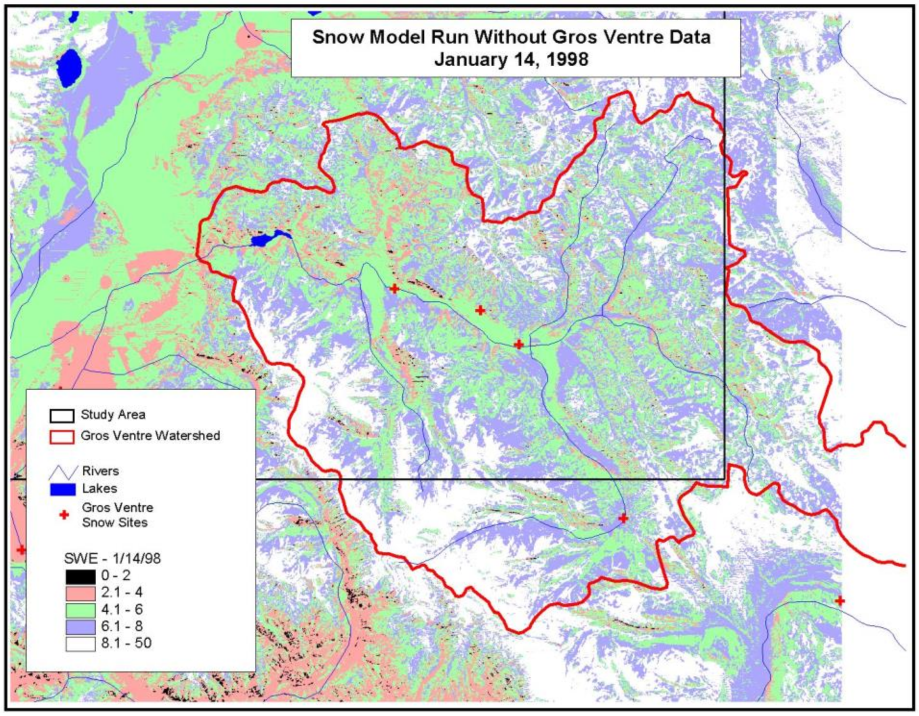

Figure 1. Snow model run without Gros Ventre data on January 14, 1998.

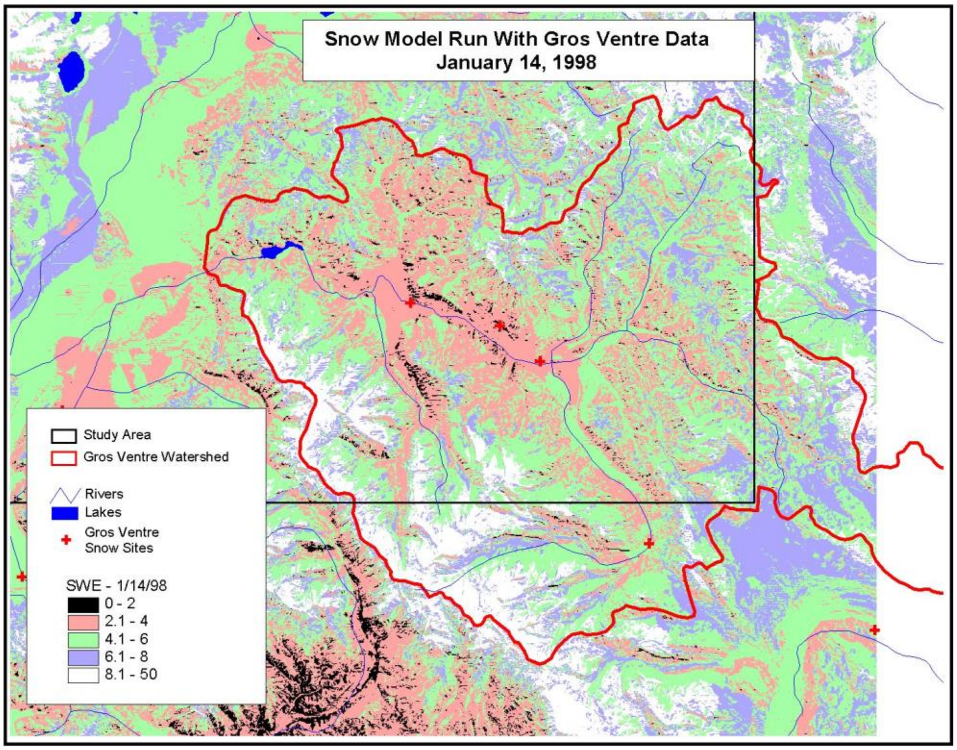

Figure 2. Snow model run with Gros Ventre data on January 14, 1998.

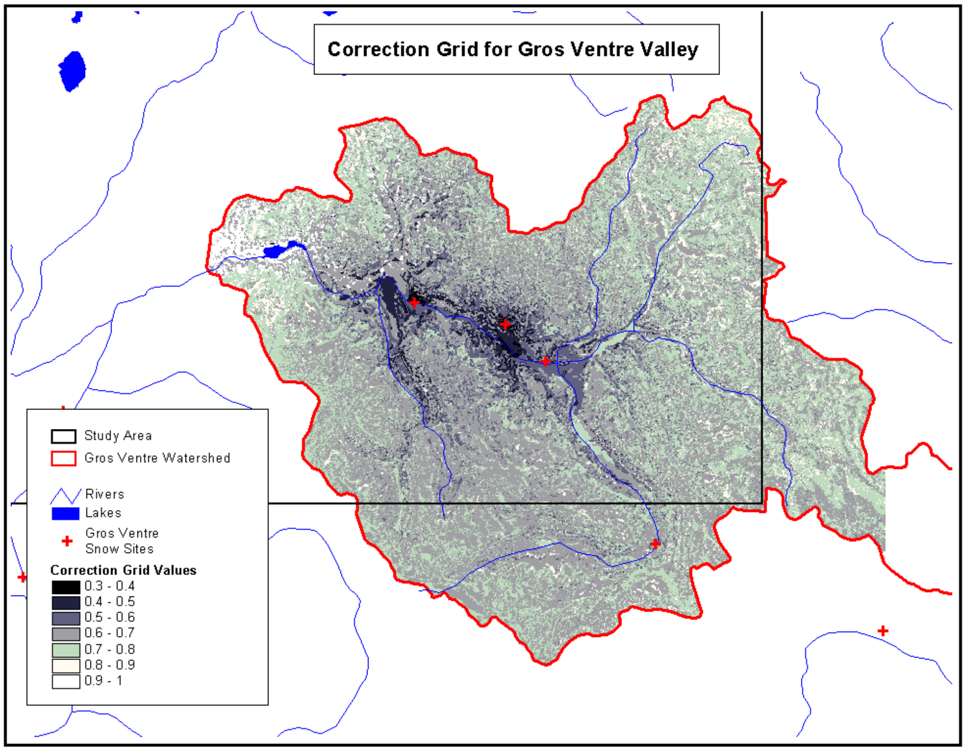

Figure 3. Correction grid for the GrosVentre valley.

Appendix C: Tables

Table 1. Vegetation Coverage Crosswalk Table

	Utah State			NER		GTNP		Our Model
CODE	COVER_TYPE	Canopy	CODE	COVER_TYPE	CODE	COVER_TYPE	**CODE**	COVER_TYPE
	Conifer Trees			**Woodlands**		**Trees (successional stage)**		**Trees**
1	alpine fir	<30%					**1**	Spruce-fir
2	alpine fir	30-59%						
3	alpine fir	>59%						
8	alpine fir/lodgepole pine	30-59%						
9	alpine fir/lodgepole pine	>59%						
10	alpine fir/spruce	<30%			40	Spruce-Fir(0)		
11	alpine fir/spruce	30-59%			41	Spruce-Fir(1)		
12	alpine fir/spruce	>59%			42	Spruce-Fir(2)		
46	spruce, englemann	30-59%			43	Spruce-Fir(3)		
47	spruce, englemann	>59%			44	Spruce-Fir(4)		
14	alpine fir/whitebark	30-59%						
16	doug fir	<30%			20	Douglas-Fir(0)	**2**	Douglas Fir
17	doug fir	30-59%			21	Douglas-Fir(1)		
18	doug fir	>59%			22	Douglas-Fir(2)		
					23	Douglas-Fir(3)		
					24	Douglas-Fir(4)		
23	doug fir/lodgepole pine	30-59%	21	PSEUDOTSUGA MENZIESII-PINUS CONTORTA				
5	alpine fir/doug fir	30-59%						
6	alpine fir/doug fir	>59%						
32	juniper, utah	30-59%	20	JUNIPERUS SCOPULORUM-AGROPYRON	64	Open_Woods/Juniper		
67	maple	>59%						
70	mountain mahogany	30-59%						
71	mountain mahogany	>59%						
37	lodgepole pine	<30%			31	Lodgepole_Pine(1)	**3**	Subalpine Pine
38	lodgepole pine	30-59%			32	Lodgepole_Pine(2)		
39	lodgepole pine	>59%			33	Lodgepole_Pine(3)		
					34	Lodgepole_Pine(4)		
40	lodgepole sapling	>59%			30	Lodgepole_Pine(0)		
48	subalpine pine	<30%			50	Whitebark(0)		
49	subalpine pine	30-59%			51	Whitebark(1)		
64	aspen/conifer	30-59%			52	Whitebark(2)		
					53	Whitebark(3)		
					54	Whitebark(4)		
52	doug fir/limber pine	30-59%						
60	aspen	<30%	16	POPULUS TREMULOIDES-CALAMAGROSTIS RUBESCENS	70	Aspen(0)	**4**	Aspen
61	aspen	30-59%	17	POPULUS TREMULOIDES/SYMPHORICARPOS	71	Aspen(1)		
62	aspen	>59%	18	POPULUS-TREMULOIDES-SALIX	72	Aspen(2)		
			19	POPULUS TREMULOIDES-	73	Aspen(3)		

				PSEUDOTSUGA				
					74	Aspen(4)		
111	decidious tree riparian		22	POPULUS ANGUSTIFOLIA-POA	90	Cottonwood(0)	**5**	Riparian Forest
			23	POPULUS-ANGUSTIFOLIA-ARTEMISIA TRIDENTATA	91	Cottonwood(1)		
			24	POPULUS ANGUSTIFOLIA-MIXED SHRUB	92	Cottonwood(2)		
			25	POPULUS ANGUSTIFOLIA-DECIDUOUS SHRUB	93	Cottonwood(3)		
					94	Cottonwood(4)		
112	riverine riparian				81	Mixed_Forest(1)		
					82	Mixed_Forest(2)		
					83	Mixed_Forest(3)		
					84	Mixed_Forest(4)		
	Shrubs			**Shrublands**		**Shrubs**		**Shrubs**
75	big sagebrush		9	ARTEMESIA TRIDENTATA -POA (on flats)	13	Dry_Sagebrush	**6**	Sagebrush
			10	AR- TRIDENTATA-AR-TRIPARTITA (grass on slopes)				
			15	ARTEMISIA TRIDENTATA-BROMUS				
82	mountain big sage				12	Moist_Sagebrush/Cinquefoil		
					15	Moist_Sagebrush		
114	shrub riparian		12	SALIX/CAREX	11	Tall_Shrub	**7**	Shrub Riparian/Willow
			13	SALIX/BROMUS	14	Low_Willow		
					81	Tall_Shrub (>7400')		
			5	SUBIRRIGATED POA				
113	herbaceous riparian							
81	montane shrub		14	SYMPHORICARPOS-ROSA			**8**	Montane Shrub
76	bitterbrush							
77	burn shrub							
80	low sagebrush							
83	mountain low sage							
86	silver sage				57	Shrub-dominated_Avalanche_Chute		
	Herbaceous			**Grassland**		**Grasses**		**Grasses**
87	alpine shrub				63	Krumholtz		
90	alpine herbaceous				34	High_Elevation_Grassland	**9**	Alpine Herbaceous/Shrub
					51	Tundra		
92	burn herbaceous						**10**	Dry Montane Meadow/Grassland
93	clearcut herbaceous							
94	dry meadow		7	AGROPYRON-STIPA (Gros Ventre hills and slopes)	24	Dry_Forb_Meadow		
					74	Dry_Forb_Meadow (>7400')		
95	perennial grass		6	AGROPYRON POA (on flat)				
96	perennial grass slope		8	AGROPYRON/POA (Miller Butte)	35	Dry_Grassland/Meadow		
97	perennial grass montane				42	Dry-Moist_Forest_Opening		
					33	Moist_Grassland/Meadow		
					73	Moist_Grassland/Meadow (>7400')		
98	tall forb montane				21	Forb_Dominated_Seep		
					22	Wet_Forb_meadow		
					82	Wet_Forb_Meadow (>7400')		

					23	Moist_Forb_Meadow		
					58	Graminoid/Forb-dominated_Avalalanche Chute		
99	wet meadow		11	POTENTILLA-FRUCTICOSA/CAREX	32	Wet_Meadow	**11**	Wet Meadow
					72	Wet_Meadow (>7400')		
					41	Wet_Forest_Opening		
	Wetland			**Wetlands**		**Wetland**		**Wetland**
120	deep marsh						**12**	Wetland/Sedge Marsh
121	shallow marsh		3	CATTAIL/ (TYPHA-SCIRPUS)	71	Marsh/Fen (>7400')		
			4	CAREX-JUNCUS	31	Marsh/Fen		
122	aquatic bed							
123	mud flat							
	Miscellaneous			**Other**		**Other**		**Other**
107	water		1	Pond	55	Water_Body	**13**	Water/Rock/Snow
			2	Stream	54	Water_Course		
101	barren				56	Cliff		
104	rock				52	Bedrock		
					53	Talus		
108	snow							
	Land-use			**Cultivated Fields**		**Agricultural**		**Agricultural**
126	agricultural		26	BROMUS INERMIS-MEDICAGO SATIVA	59	Agricultural	**14**	Agricultural
			27	BROMUS INERMIS-MIXED GRASS				
			28	ELYMUS JUNCEUS				
			29	ELYMUS CINEREUS				
			30	POA PRATENSIS				
			31	AGROPYRON-MIXED GRASS				
			32	ALOPECURUS ARUNDINACEUS				
			33	PHLEUM PRATENSIS-POA				
			34	AGRPPYRON INTERMEDIUM				
			35	AGROPYRON ELONGATUM				
129	disturbed, high						**15**	Developed/disturbed
130	disturbed low							
131	urban, high density				60	Human_Development		
132	urban, low density							

Table 2. Conversions of U.S. Forest Service production classes used in this analysis.

Class	Production range (lbs/acre)	Midpoint used for analysis (lbs/acre)
0	No production	0
1	1-50	25
2	50-300	175
3	300-500	400
4	500-750	625
5	750-1200	975
6	1200-2500	1850
7	2500-4000	3250
8	4000+	6000

Table 4. Offtake Calculations

Spreadsheet for calculating Pounds Offtake from Animal Numbers						
Actual numbers Year 2000 -- 12,771 elk						
Elk	**Number of Animals**	**Average Weight (lbs)**	**Total Animal Pounds**	**Daily Offtake**	**Weekly Offtake**	**Elk % of Total**
Juveniles	1915	200	383000			0.1499491
Yearlings	646	350	226100			0.0505834
Adults (F)	8354	500	4177000			0.6541383
Adults (M)	1856	675	1252800			0.1453293
Total	12771	1725	6038900	120778	905835	
Moose						
Calves	162	200	32400			
Cows	466	700	326200			
Bulls	261	1300	339300			
Total	889	2200	697900	13958	104685	
Bison						
Calves	50	350	17500			
Yearlings	100	600	60000			
Cows	150	1350	202500			
Bulls	200	2000	400000			
Total	500	4300	680000	13600	102000	
			Total Weekly Offtake		**1112520**	
With 6,000 Elk						
Elk	**Number of Animals**	**Average Weight (lbs)**	**Total Animal Pounds**	**Daily Offtake**	**Quarter-month Offtake**	**Elk % of Total**
Juveniles	900	200	179938			0.1499491
Yearlings	304	350	106225			0.0505834
Adults (F)	3925	500	1962414			0.6541383
Adults (M)	872	675	588583			0.1453293
Total	6000	1725	2837162	56743	425574	
Moose						
Calves	162	200	32400			
Cows	466	700	326200			
Bulls	261	1300	339300			
Total	889	2200	697900	13958	104685	
Bison						
Calves	50	350	17500			
Yearlings	100	600	60000			

Cows	150	1350	202500			
Bulls	200	2000	400000			
Total	500	4300	680000	13600	102000	
			Total Weekly Offtake		**632259**	

Table 5. Vegetation Code Crosswalk Table

Vegetation Type (Utah State)	**Percent Cover**	**Snow Model Code**
alpine fir	<30%	21
alpine fir	30-59%	22
alpine fir	>59%	24
alpine fir/doug fir	30-59%	22
alpine fir/doug fir	>59%	24
alpine fir/lodgepole pine	30-59%	22
alpine fir/lodgepole pine	>59%	24
alpine fir/spruce	<30%	21
alpine fir/spruce	30-59%	22
alpine fir/spruce	>59%	24
alpine fir/whitebark	30-59%	22
doug fir	<30%	41
doug fir	30-59%	42
doug fir	>59%	44
doug fir/lodgepole pine	30-59%	42
lodgepole pine	<30%	33
lodgepole pine	30-59%	31
lodgepole pine	>59%	32
lodgepole sapling	>59%	30
spruce, englemann	30-59%	22
spruce, englemann	>59%	24
subalpine pine	<30%	51
subalpine pine	30-59%	52
doug fir/limber pine	30-59%	42
aspen/conifer	30-59%	34
Vegetation Type GTNP (successional stage)		
Lodgepole Pine (0)		30
Lodgepole Pine (1)		31
Lodgepole Pine (2)		32
Lodgepole Pine (3)		33
Lodgepole Pine (4)		34
Spruce/Fir (0)		20
Spruce/Fir (1)		21
Spruce/Fir (2)		22
Spruce/Fir (3)		23
Spruce/Fir (4)		24
Douglas Fir (0)		40
Douglas Fir (1)		41
Douglas Fir (2)		42
Douglas Fir (3)		43
Douglas Fir (4)		44
Whitebark Pine (1)		50
Whitebark Pine (2)		51

Whitebark Pine (3)	52
Whitebark Pine (4)	53
Whitebark Pine (5)	54
Vegetation Type NER	
Pseudotsuga Menziesii/Pinus Contorta	32

Table 6. Snow Sites, Elevation, Location

Site #	Elevation (meters)	UTM east	UTM north	Name
1	1895.00	519300	4814300	/Jackson
2	1966.00	522900	4833400	/Moose
3	2075.00	533100	4855800	/Moran
4	2148.00	544800	4865500	/Basecamp
5	2574.00	508200	4818100	/Phillips bench
6	2900.00	575000	4844600	/Togwotee pass
7	1974.00	519180	4831640	/Boys Ranch
8	1973.00	518910	4831620	/Death Canyon
9	1955.00	518330	4830630	/RLazy S
10	1962.00	517360	4829690	/Wilson Road
11	1965.00	522980	4833440	/Moose W.S.
12	2017.00	521470	4836720	/Beaver Creek
13	1986.00	524570	4834260	/Blacktail Butte
14	2092.00	531120	4844660	/Deadman's Bar Rd
15	2072.00	536830	4848150	/Moosehead Ranch
16	2047.00	539250	4852900	/N. Elk Ranch
17	2048.00	539180	4854300	/Buffalo R.S.
18	2056.00	536480	4856860	/Oxbow Bend
19	2092.00	544870	4853780	/Buffalo Valley R
20	2083.00	545740	4854830	/Road 30083
21	2107.00	546590	4855490	/Buffalo Run
22	2072.00	548180	4853110	/KOA Picnic Area
23	2100.00	552210	4852300	/Black Rock R.S.
24	2013.00	527170	4834620	/Antelope Flat
25	2067.00	529600	4835550	/Mailbox Corner
26	2046.00	529620	4837780	/Schwering Studio
27	2108.00	531930	4834670	/Lobo Hill
28	2026.00	530450	4829060	/Highlands Jct
29	2024.00	528200	4828730	/Highlands Loop
30	1958.00	521490	4827770	/Airport
31	1976.00	524720	4827510	/Gros Ventre Rive
32	1939.00	521550	4823160	/Gros Ventre Turn
33	1900.00	521580	4820200	/Fish Hatchery
34	1895.00	519420	4814490	/Jackson W.S.
35	1908.00	520480	4814080	/NER HQS
36	2044.00	522090	4839860	/Lupine Meadows
37	2099.00	522290	4847720	/Jenny Lake Lodge
38	2115.00	524050	4848370	/N. Jenny Lake Jc
39	2098.00	530950	4852040	/Sewage Ponds
40	2065.00	520700	4857000	/Moran Bay SC
41	2102.00	533860	4860760	/Pilgrim Creek
42	2084.00	529440	4861970	/Coulter Bay
43	2070.00	529790	4835310	/Hunter Hay WE
44	2100.00	530990	4835510	/Hunter Hay NS

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45        1977.00     522120    4834280 /Bar BC Road
46        2023.00     523420    4838230 /Bar BC Road B
47        2022.00     523920    4838180 /Bar BC Mid
48        1983.00     524770    4837980 /Bar BC FP
49        2025.00     523020    4838280 /Bar BC Mid RD
50        2094.00     531450    4851700 /RKO Road Flats
51        2095.00     536450    4859500 /RKO PL
52        2040.00     535500    4851200 /RKO Willow Flat
53        1938.00     513860    4825940 /Ski Area Base
54        1954.00     511080    4820820 /Phillips Canyon
55        2138.00     532700    4835100 /Elbo Ranch
56        2393.00     558800    4852100 /Four Mile Meadows
57        2106.00     558200    4856100 /Turpin Meadows
58        2668.00     570500    4804200 /Gros Ventre Summit
59        2312.00     519600    4811900 /Snow King Mountain
60        2243.00     525000    4876800 /Huckleberry Divide
61        2150.00     521100    4882800 /Glade Creek
62        2456.00     502700    4816300 /Teton Pass W.S.
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TABLE 7. STATION ASSIGNMENT FOR REGRESSION FUNCTION

PREDICTOR STATIONS		
Jackson	Moose, Moran	Base Camp, Phillips Bench, Togwotee Pass
PREDICTED STATIONS		
Buffalo Valley Road Fish Hatchery Jackson W.S. NER H.Q.	Death Canyon, R Lazy S Boys Ranch, Wilson Road Buffalo R. S., Moose W.S. Beaver Creek, Blacktail Butte Deadman's Bar, Moosehead Ranch N. Elk Ranch, Road 30083 Buffalo Run, KOA campground Blackrock, Antelope Flat Mailbox, Schwering Studio Lobo Hill, Oxbow Bend Highlands Jct., Highlands Loop Airport, Gros Ventre River Gros Ventre Turnout, Lupine Meadows Sewage Pond, Pilgrim Creek Coulter Bay, Hunters Hayfield WE Hunters Hayfield NS, Bar BC Road Bar BC Road B, Bar BC Mid Bar BC FP, Bar BC Mid Road RKO Road Flats, RKO PL RKO Willow Flat, Ski Area Base	Jenny Lake Lodge N. Jenny Lake Jct. Moran Bay S.C. Phillips Canyon Snow King Mountain Huckleberry Divide Glade Creek Teton Pass W.S. Gros Ventre Summit