The Habitat Assessment Model: A Tool to Improve Wildlife Habitat Management

L. R. Roath[1], E.M. Hardy[2], G. Wockner[2], S. Porter[3], N.T. Hobbs[2], and D. Freddy[3]

1. Department of Forest, Range and Watershed Stewardship, Colorado State University, Fort Collins, CO
2. Natural Resource Ecology Lab, Colorado State University, Fort Collins, CO
3. Colorado Division of Wildlife, Fort Collins, CO

Acknowledgements:

The authors would like to thank the Colorado Division of Wildlife for providing funding, through the Habitat Partnership Program, to this project. The North Park Habitat Partnership Committee also contributed valuable time and effort through their work as a pilot study site for the Habitat Model. The authors would also like to thank the Habitat Partnership Program Statewide Council for their continued support. The Natural Resource Ecology Lab at Colorado State University and the Forest, Range, and Watershed Stewardship Department at Colorado State University also provided support and facilities for this project.

Table of Contents

I. Introduction

Natural resource managers are faced with a complex and dynamic set of challenges. In order to set and meet wildlife population objectives, it is necessary to understand complex habitat relationships and make sound land management decisions. Many ecosystem processes including disturbance, wildlife movement, and nutrient cycling transcend administrative boundaries. As a result, the management actions taken on public lands cannot be separated from the impacts on adjacent private lands and vice versa (Yaffee and Wondolleck 1997). To effectively manage at the ecosystem level it is necessary for public and private land managers to collaborate and discuss management goals for their adjacent lands. Development of common ground and a straightforward decision making framework to facilitate the implementation of sound habitat management practices is critical.

In an effort to resolve fence and forage conflicts on private and public lands, the Colorado Division of Wildlife (CDOW) created the Habitat Partnership Program (HPP). In the winter of 1988-89 concerns over increasing populations of big game and the ensuing fence and forage damages pushed Colorado agricultural groups to propose new legislation to expand CDOW liability for game damages. The two main points of contention were 1) farmers and ranchers were concerned with the ineffectiveness of the Division of Wildlife's Game Damage Program to provide proper and timely compensation for damages and 2) a lack of appropriate landowner input in the development of wildlife herd management objectives. In response, the CDOW director proposed new legislation that eventually led to the formation of the HPP program. Initially created in 1990 as a means to address concerns of big game damage to fence and forage on private lands in Colorado, the HPP has evolved over time. Presently, HPP committees not only resolve fence and forage conflicts, but also focus on habitat improvement projects affecting both private and public lands.

The Habitat Partnership Program was revised and reauthorized in 2001. This new legislation requires that an assessment of the habitat capability be completed. The Habitat Assessment Model has been designed as a tool to aid HPP committees in discerning the relationships between wildlife populations and habitat sustainability. General habitat based management principles have been incorporated into a clear, straightforward model utilizing ArcView GIS technology. This model has been designed to be a transparent, easy to use, decision-making tool that incorporates year to year variation in vegetation production and winter severity levels into a modeling scenario. The model includes existing information generated by local, state and federal government agencies as well as critical input from local community members. Every effort has been taken to include local knowledge in the modeling process, thereby strengthening the ties between the model and the real world.

The overall goal of this modeling project is to provide the users with a tool capable of examining the relationships between wildlife population numbers and habitat sustainability. The Habitat Model produces a range of population values with related management implications that can be used in the DAU planning process.

II. Theoretical Background

A. Habitat Management

Habitat refers to a landscape and an environment suited to meet the needs of a particular species. An **ecological niche** is the space and methods within an ecosystem a species uses to exploit habitat resources to survive and reproduce. Since each species utilizes a different ecological niche, many species coexist within a habitat. The quantity and quality of available resources within a habitat are dynamic and change with many factors including precipitation, disturbance, and grazing. Changes in the supply or quality of resources within a habitat will control the population size that can be supported by that habitat. Many species utilize different habitats throughout the year, and are limited by the habitat that supplies the least amount of a necessary resource relative to their needs. For example, winter range limitations can control elk population size even if spring and summer ranges can support much larger populations.

B. Succession

Frederic Clements first proposed the concept of succession in 1916 as the orderly replacement of one plant community by another in a defined series (Clements 1916). Dyksterhuis further applied this concept to grasslands by (Dyksterhuis 1949). This view of succession holds that all rangelands have a single persistent (climax) state in the absence of disturbance, and sites steadily progress from early seral communities to late seral or climax communities.

This idea of succession further held that disturbances drive the system in the opposite direction of the climax state. Therefore, it is theoretically possible to balance the natural progressive tendency to move towards a climax community with grazing pressures that move the community towards earlier seral stages. The magnitude of force acting to move the community towards earlier seral stages would be correlated to stocking rate, with higher stocking rates generating greater retrogressive forces. The result would be a community held in stasis by the balance between grazing intensity and natural successional forces (Westoby et al. 1989).

Although forming the basis for current thought, the view of succession as a linear continuum has lost prominence because too many variables affect plant communities to view succession as a linear process. As a result, Westoby et al. (1989) proposes that a "State and Transition model" is more reflective of the successional process.

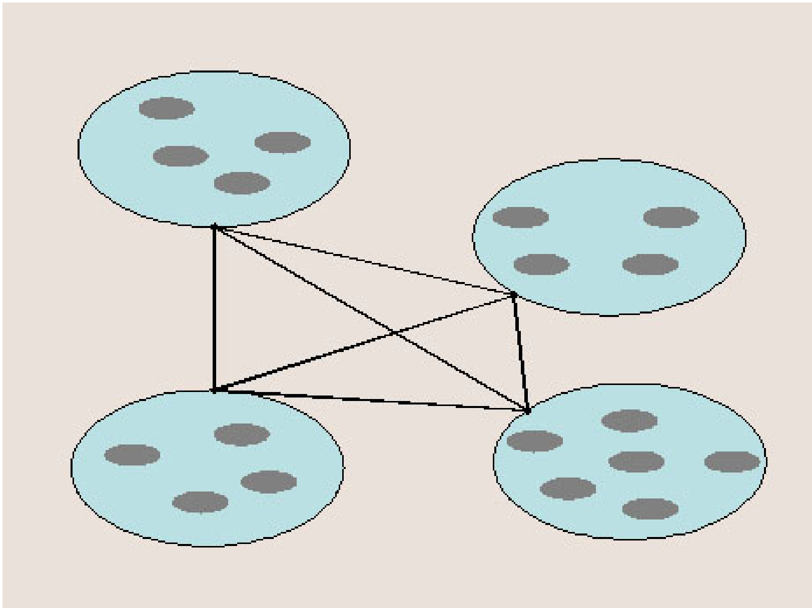

Figure 1. Theoretical Representation of the State and Transition Model- The large light gray circles represent states, the lines between circles represent possible transition pathways, and the small dark gray ovals represent different species compositions within a state.

States, depicted by large gray circles, represent relatively stable, general assemblages of plant species that occupy a site. States are general and can be represented by numerous sets of species assemblages. These different assemblages are characterized by the dark grey gray ovals in Figure 1. It is possible to transition between assemblages while still remaining in the same overall state. Examples of states include annual dominated grasslands, perennial dominated grasslands, and shrublands, while Stipa comata/Bouteloua gracilis grassland, Agropyron spicatum/Agropyron smithii grassland, and Artemisia tridentate/Festuca scabrella shrubland all represent assemblages. Transitions are pathways between states that can be triggered by different actions. These are shown as black lines in Figure 1, and can result from natural events like fire or weather, or by management actions such as changes in stocking rate, burning, fertilization, or the destruction or introduction of species. Transitions may occur abruptly, as with fire, or may occur over extended periods of time. A system does not come to rest halfway through a transition, but always comes to rest within a state (Westoby et al. 1989).

C. Practical Applications

The State and Transition model provides a useful planning tool for managers. After defining the states and transitions within a system, managers can use manipulation tools, such as grazing, burning, or fertilization, to influence transitions into more desirable states. Managers can also recognize when natural climatic conditions combine with other influences, such as grazing, to create a cumulative influence on the vegetation and landscape, and can make management changes to adjust impacts accordingly.

The habitat model provided with this manual allows users to simulate interactions between climate, annual vegetation production, and wild ungulate grazing intensity. By coupling these modeling scenarios with the appropriate understanding of states and transitions for the ecosystems being modeled, predictive results can be made about the interaction of different wild ungulate population levels and their influence on the affected ecosystems. This model should only be viewed as one of many tools that a land manager can use. Public and private land managers still need to constantly appraise the condition of the land and make management decisions on issues such as stocking rates (for both domestic and wild ungulates) and use of disturbance (fire, herbicide, mechanical manipulation) to ensure the land can meet the demands placed upon it without creating long-term degradation. Management decisions need to be reviewed and modified to address the changing conditions generated by changes in weather.

D. Grazing Effects

The defoliation of plants by eating and trampling, redistribution of materials through waste deposition, and general movement patterns of domestic and wild ungulates all influence rangelands. **Defoliation** refers to the removal of physiologically active material, as by herbivore eating, clipping, and trampling (Heady and Child 1994). The affects of defoliation and the plant's response to this event are dependent upon three key variables: frequency of defoliation, intensity of defoliation, and the opportunity for regrowth following a defoliation event. Frequency is a measure of the number of defoliation events during a growing season. Frequency is interrelated with intensity and regrowth opportunity, but generally, increased frequency provides less opportunity for regrowth and can be detrimental to the plant. Grazing intensity represents the proportion of the current year's growth removed by the grazing event. As the amount of plant material removed increases, less leaf area remains for energy capture to fuel regrowth. In severe defoliation, cessation of growth can occur causing the plant to draw on stored reserves. This results in a loss of growth potential for the immediate growing season, and potentially, ensuing seasons as well. The opportunity for regrowth is a function of the seasonality of the defoliation event and it is directly correlated with the relative capability of the plant to achieve a full array of leaves and complete full energy storage each year. Soil water availability and photosynthetic leaf area both play a role in regrowth potential. For example, many grass species are most sensitivity to defoliation when their flowering stalks begin to develop, with sensitivity decreasing rapidly as the plants approach maturity (Heady and Child, 1994). By understanding the interactions of these three variables for controlling the impacts of defoliation, managers can design strategies to minimize the impacts of grazing and use grazing as a habitat management tool (Reed et al. 1999).

E. Comparing Domestic and Wild Ungulate Grazing

Although this model does not directly address the effects of foraging strategy differences between domestic and wild ungulates, it is important to incorporate an understanding of these differences into the decision making process. Archer and Smeins (1991) provide a discussion of some differences between domestic and wild ungulate foraging strategies.

For example, unlike wild herbivores, whose numbers and patterns of distribution can vary annually, domestic livestock concentrations can be artificially maintained at consistently high levels because their stocking rate is controlled by the manager. The use of fences prevents domestic livestock from moving to new areas when the abundance of desirable forage is depleted, which can result in higher frequencies and intensities of defoliation than would occur naturally. Unlike wild ungulates, domestic ungulates can receive the benefit of supplemental feeding when range forage is limited. This supplemental feeding interrupts the natural feedback loop that exists between low forage availability and increased animal mortality and decreased fecundity that helps to limit wild populations when resources are scarce. Although the natural forage limitation feedback loop is interrupted by domestic livestock, the advantage exists that domestic livestock can be removed from the system when forage supplies are exceeded. Wildlife managers can also remove wild ungulates by increasing allowable harvest numbers.

The key concept of this process is that the land has a finite and limited capability to provide forage for a mixed group of grazers. When that limit is reached or exceeded, there are ecological and animal performance consequences. The greatest dependability and the lowest risk of negative ecological and animal performance occur at moderate stocking rates that fall well below the threshold of maximum capacity. This relationship reflects year to year variability in forage availability and forage quality, as well as variability in determining reliable estimates of actual grazing animal populations.

The focus of the Habitat Model is to take many of the concepts just discussed and incorporate them into a simple model. This task is difficult, and an understanding of the theoretical background of the model will allow the user to more accurately assess the implications of the Habitat Model results. The data used in the Habitat Model also forms a critical component, and Section III provides a review of the methods used in the data gathering process.

III. Data Input Sources for the Habitat Model

Gathering and processing information to generate the Habitat Model is one of the more difficult steps in the modeling process. Data sources need to be gathered, interpreted, manipulated and properly formatted and some new data has to be generated. This section will outline data needs and suggest sources and methods for collecting the necessary data. A case study has been included with this manual to provide a specific example of this process. There are four general areas in which data is needed. These are:

A. Vegetation Production Values
B. Wildlife Winter Range Polygons
C. Additional Wild Ungulate Offtake from Non-Target Species Other Than Elk and Mule Deer
D. Livestock Offtake

Each of these will be addressed below.

A. Production Values

Production values are critical to the model since they determine the quantity of forage available for consumption by both domestic and wild ungulates. A number of different vegetation coverages exist, but in order to be useful, there must be a production value associated with the vegetation type. The three most available data sources from general to specific are:

1. **State Soil Survey Geographic Database (STATSGO)-** Soil maps for the STATSGO database are produced by the USDA-NRCS Soil Survey Division, and are derived by generalizing detailed soil survey data. STATSGO maps use a scale of 1:250,000 (with the exception of Alaska, which is 1:1,000,000). To generate these maps, the entire map area is divided into a number of polygons representing the underlying soil types. Each soil type is associated with a broad range-site type and a production value for that range site. These range-site types and production values are based on sampling from representative sites in good seral condition. It may be necessary to modify these production values to more accurately reflect local conditions. These modifications should be made by someone with knowledge and expertise in the range evaluation field. To use this data, competency in importing and manipulating data in Arcview and Microsoft Excel or Microsoft Access is necessary. As of 2003, the source for STATSGO data is: U.S. Department of Agriculture, Natural Resource Conservation Service. "State Soil Geographic (STATSGO) data base for Colorado." 1994. 15 December 2002. http://www.ftw.nrcs.usda.gov/statsgo_metadata/co.html

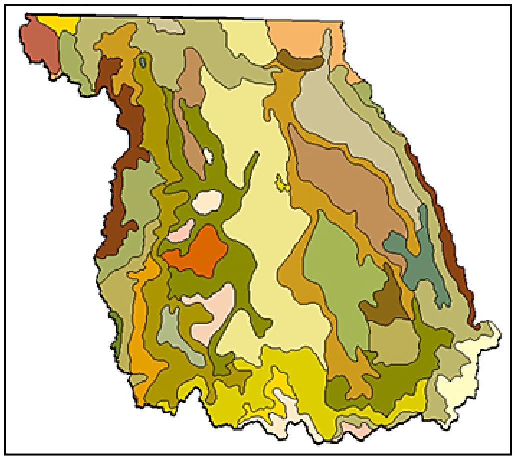

Figure 2. Example of a STATSGO coverage.

2. **Soil Survey Geographic Database (SSURGO)-** The information contained within this database is similar in structure to that of STATSGO, however, this data is formed from the county level soil survey. One result of this is that many of the soils that were aggregated to form one soil polygon at the STATSGO level are now divided into numerous soil polygons, thereby increasing the complexity of the soils map. This serves to increase the resolution of the range site production estimates and may increase the accuracy of the production estimates at smaller geographic scales. SSURGO data is currently not available for all areas within the U.S. The USDA-NRCS is in the process of updating this information, but it is a time consuming task. Similar to STATSGO, range-site types and production values are based on sampling from representative sites in good seral condition. It may be necessary to modify these production values to more accurately reflect local conditions. An understanding of Arcview and Microsoft Excel or Microsoft Access is necessary to process the data. As of 2003, the source for SSURGO data is:
U.S. Department of Agriculture, Natural Resources Conservation Service. "National Map Unit Interpretation Record (MUIR) Database". 1994. Fort Worth, Texas. 15 December 2002.
http://ortho.ftw.nrcs.usda.gov/muir/

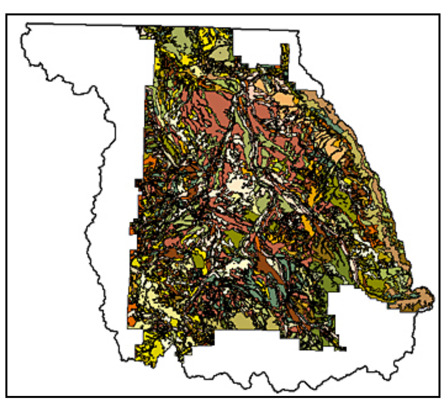

Figure 3. Example of SSURGO coverage.

3. **Local Data Sources-** The model building process requires a collaborative effort, utilizing the resources available from individuals on the HPP committee whenever possible. In some cases, government agencies or local groups may have production information that is more accurate and site specific than the information contained in either STATSGO or SSURGO. These data sources should be reviewed and used if they can be modified and imported in a time and cost effective manner. At the least, it may be possible to modify the range site production values contained in the STATSGO and SSURGO databases to more accurately reflect local conditions. Local cooperators are usually the most accurate source of information regarding livestock numbers and animal distribution information. However, caution should be taken not to overextend the scope of local data. For example, production information collected on a single allotment may not be appropriate to use as the basis for production estimates for all the allotments within a county.

Climatic variability plays a key role in determining production values. A study in northwestern Colorado showed that 70 percent of the variability in annual net primary production (ANPP) was the result of climatic variability (Hobbs et al. 1996). To capture this variability in the Habitat Model, representative values for years of low, average, and high annual net primary production are necessary. Regardless of data source, all production values used in the Habitat Model should be standardized to the following descriptions from the USDA-NRCS (U.S. Department of Agriculture, Natural Resources Conservation Service (1994).

1. **Below Average Production-** The estimated annual potential production of range forage for the soil in a year of unfavorable or below average growing conditions, rounded to the nearest 100 pounds.
2. **Average Production-** The estimated annual potential production of range forage for the soil in a year with normal or average growing conditions, rounded to the nearest 100 pounds.
3. **Above Average Production-** The estimated annual potential production of range forage for the soil in a year with above average growing conditions, rounded to the nearest 100 pounds.

B. Winter Range Polygons

Winter range polygons predict the distribution of wild herbivores across the landscape based on the severity of winter conditions. These winter range polygons are used to determine the amount of forage available to wintering populations of elk and mule deer (moose and pronghorn will be discussed later). The Habitat Model uses a combined winter range distribution for elk and mule deer. Three winter range distributions for elk and mule deer are needed to build the Habitat Model. These distributions are:

1. **Mild Winter Range**- That part of the overall range described by the committee as being the total potential winter range available.
2. **Average Winter Range**- That part of the overall range where 90 percent of the individuals are located during the average five winters out of ten from the first heavy snowfall to spring green-up, or during a site specific period of winter as defined for each DAU.
3. **Severe Winter Range**- That part of the overall range where 90 percent of the individuals are located when the annual snowpack is at its maximum and/or temperatures are at a minimum in the two worst winters out of ten.

The DOW currently collects and maintains this distribution data for many wildlife games species in Colorado. This data set resides under the Wildlife Resource Information System (WRIS) established by the CDOW in 1974 and is available online from the CDOW Natural Diversity Information Source (NDIS) website. However, this data set should not be used for elk and mule deer in the Habitat Model. To ensure the winter range distributions accurately reflect current conditions, and to include input from all HPP committee members on the winter range polygons, re-mapping of winter range polygons should occur using SMART Board technology. The DOW GIS team currently uses this technology to update WRIS data sets and it has proven effective in the Habitat Model pilot study. Using this technology, field personnel edit/enter map features directly into a Geographic Information System (GIS) by simply drawing on base maps projected onto an interactive whiteboard. With the assistance of the GIS specialist, there is no need for the field personnel to have prior GIS experience. Map layers can be panned, zoomed and queried to assist the managers as they draw habitat boundaries on the whiteboard (Cowardin and Flenner 2003). The equipment for this process consists of a laptop, computer projector, external storage drive and a 60-inch interactive SMART Board with a floor stand and carrying case. The mapping process is as follows:

1. The DWM and the GIS specialist review the current WRIS maps and make any changes necessary to reflect current winter range distributions. Only the DWM is included during the initial modification of the data to streamline the initial editing process.
2. After the DWM completes the initial editing process, the entire HPP committee reviews the winter range distributions. During this time, the entire committee should thoroughly review the distributions and discuss any issues that arise. Changes should be made based on committee member input, and the distributions should be finalized.
3. The entire committee should now agree on the validity of the winter range polygons.

Figure 4. SMART Board Mapping Process.

After the mapping process is complete the modeler must then import the polygons into Arcview and edit them into the proper format. For the Habitat Model the distributions of elk and mule deer are combined to create one set of mild, average, and severe winter range polygons for both elk and mule deer (Figure 5).

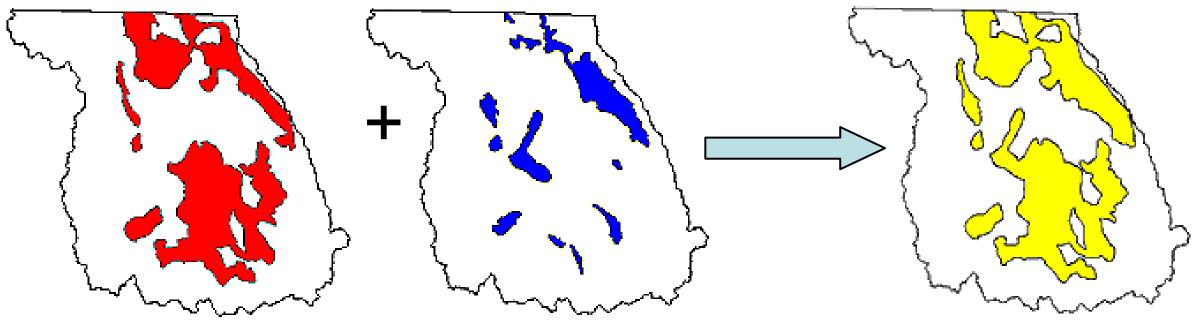

Figure 5. Creation of Winter Range Polygons. The winter range for elk is combined with the winter range for mule deer to generate a combined winter range polygon used in the Habitat Model.

C. Non-Target Wild Ungulate Offtake

In most areas there are going to be wild ungulates other than mule deer and elk consuming forage. To include these animals in the Habitat Model, an offtake map accounting for their forage use is generated. The WRIS data mentioned before should contain shapefiles detailing the overall range and winter range for all species which fall into this category and are relevant to the scope of this modeling process. These WRIS maps, combined with estimates of current population numbers provided by the DOW, are used to generate forage offtake maps for these species. The process for generating offtake maps for one of these species is as follows:

1. Obtain the WRIS shapefiles of overall range and winter range for each species from the Natural Diversity Information Source (NDIS) website http://www.ndis.nrel.colostate.edu or by contacting the DOW GIS Unit.
2. Get an estimate of current population numbers from the DWM or from the Habitat Biologist responsible for that area.
3. Calculate the total forage demand generated by the estimated population. Figure 6 provides the average body weight estimates for the wild ungulate species used in the Habitat Model. Average daily forage demand for grazing ungulates varies from 2.5 percent pf body weight during active forage growth to 1.5 percent during forage dormancy (Holechek and Pieper 1992). To account for this range,

2 percent of the average body weight of an individual animal per day is used in the Habitat Model. See Figure 7 for an example of this calculation.

Wild Ungulate	Average Body Weight per Individual
Pronghorn Antelope	100 lbs
Moose	1000 lbs
Elk	500 lbs
Mule Deer	150 lbs

Figure 6. Sample Average Body Weights for Wild Ungulates Used in the Habitat Model- Average weight for all individuals within a population. Estimates based on information from Wassink (1993).

4. The forage demand generated in step 3 now needs to be allocated across the landscape. To do this the demand created by the entire population is distributed equally across all of the land within the overall range for 6 months and then across only the land in the winter range for six months. For example, using Figure 6, the demand on the overall range from our pronghorn population would be 91,250 lbs (representing 6 months of demand), and the demand on the winter range would be 91,250 lbs (also representing 6 months of demand).
5. Once the forage demand for the overall range and the winter range has been calculated, the information needs to be converted into an offtake grid. To accomplish this, the modeler needs to determine the total area within the overall range and the winter range, respectively. The total area for each range is then divided by the total demand in pounds per acre to generate a pounds per acre offtake value. For example, let us assume that the overall range is 50,000 acres and the winter range is 25,000 acres. Based on our example above that would be 1.82 lbs/acre (91,250 lbs ÷ 50,000 acres) for the overall range and 3.64 lbs/acre (91,250 lbs ÷ 25,000 acres) for the winter range. Notice the offtake demand on the winter range is higher because the same amount of forage demand is placed on a smaller geographic area.
6. Once the pounds per acre offtake value has been determined, the modeler now converts the overall range and winter range shapefiles into one-acre grids, with each grid cell containing the appropriate offtake value. Based on our example, the overall range offtake grid cell would have a value of 1.82 and the winter range value would be 3.64, respectively. These grids are then used by the model in the calculation of the population of elk and mule deer that can be supported.
7. This process should be repeated for each additional wild ungulate (other than mule deer and elk) that is in the Habitat Model.

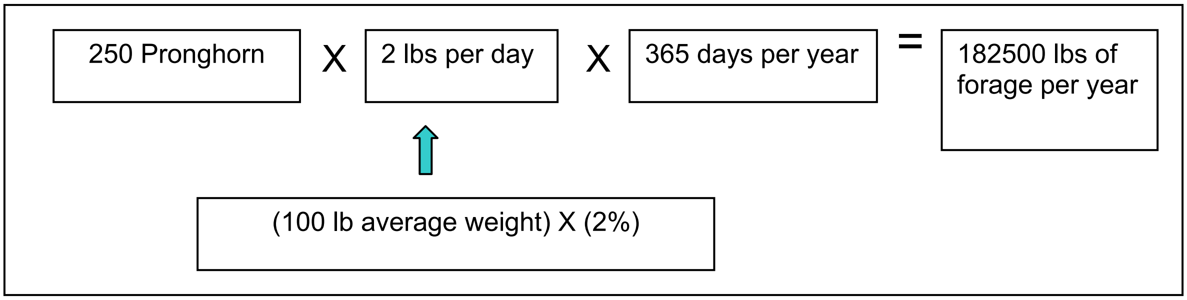

Figure 7. Example of Forage Demand Calculation for Additional Wild Ungulates. This is a theoretical example of the calculation used to determine the forage demand for 250 pronghorn antelope over the course of one year. The number of individuals in the population is multiplied by the forage demand per day. This total, representing the daily forage demand for 250 pronghorn, is multiplied by the number of days in one year to generate the total annual forage demand.

D. Livestock Offtake

Since livestock and wildlife can utilize the same areas for forage, livestock offtake needs to be included in the Habitat Model. Trying to accurately determine livestock offtake can be a difficult task since many ranching operations utilize both private and public lands at varying intensities throughout the year. The level of detail that can be captured in the modeling process results from a balance between the information available and the time-cost constraints of processing data. At the scale of resolution for the Habitat Model, the livestock offtake issue can be summed into two questions: (1)How many animals? (2)Where are they grazing? For the reasons outlined above, the process of gathering livestock offtake information will likely be unique in each modeling situation. Described below, in order from general to specific are three possible methods for collecting this information. The Habitat Model assumes each Animal Unit Month (AUM) is equivalent to 800 pounds of forage demand. The case study in Appendix 1 reviews a real world approach to this issue.

1. Determine the total number of livestock AUM's for the area being modeled, and then distribute the AUM's evenly across the entire area. Landowners and others on the HPP committee may be able to provide an estimate for livestock use. Colorado Agricultural Statistics can also provide a reasonable, general source of livestock numbers at the county level. If Colorado Agricultural Statistics must be used, consult the landowners and others on the HPP committee to ensure the numbers provided are a plausible estimate. This estimate can then be used to generate an offtake grid similar to that described for wild ungulate offtake. To create this grid the total demand generated by the AUM's would be divided by the total land area, resulting in a fixed number of pounds per acre being removed across the entire area being modeled.
2. Determine the total number of livestock AUM's for the area being modeled and then ask the committee to distribute the animals across the landscape. Using this method, committee members would divide the area into a number of smaller subunits. AUM's would be distributed into these subunits based on information from the committee, resulting in varying levels of forage offtake across the area being modeled. This method provides a more detailed picture of livestock

offtake because it distributes grazing pressure in a more realistic manner across the landscape. An example of this method is provided in the case study in Appendix 1.

3. Utilize localized livestock grazing data and offtake maps provided by government agencies combined with utilization information from local landowners. Although this method may provide the most accurate livestock offtake information, it is the most difficult and time consuming to collect. Much of the information provided by the agencies must be manipulated into a usable GIS format, and many landowners may not be willing to provide this information. This method would be most useful when dealing with a few, willing landowners and government agencies that already have grazing information in a usable format.

Each modeling effort will be different, and the method used to gather livestock offtake information will be dictated by the situation. It may be necessary to use a combination of the methods described above. The overall goal is to try and obtain the most realistic distribution of livestock offtake possible in the most efficient manner.

IV. Model Design

The habitat model was designed to be a simple, transparent tool to facilitate the implementation of sound habitat management practices. Wildlife population management decisions have typically been based on population models. These population models often provide minimal information regarding the feedbacks that exist between herbivory and vegetation (Weisberg et al. 2002). This model uses simple forage accounting theory, and all calculations rely on simple arithmetic. The following figure depicts the logic used in the model design.

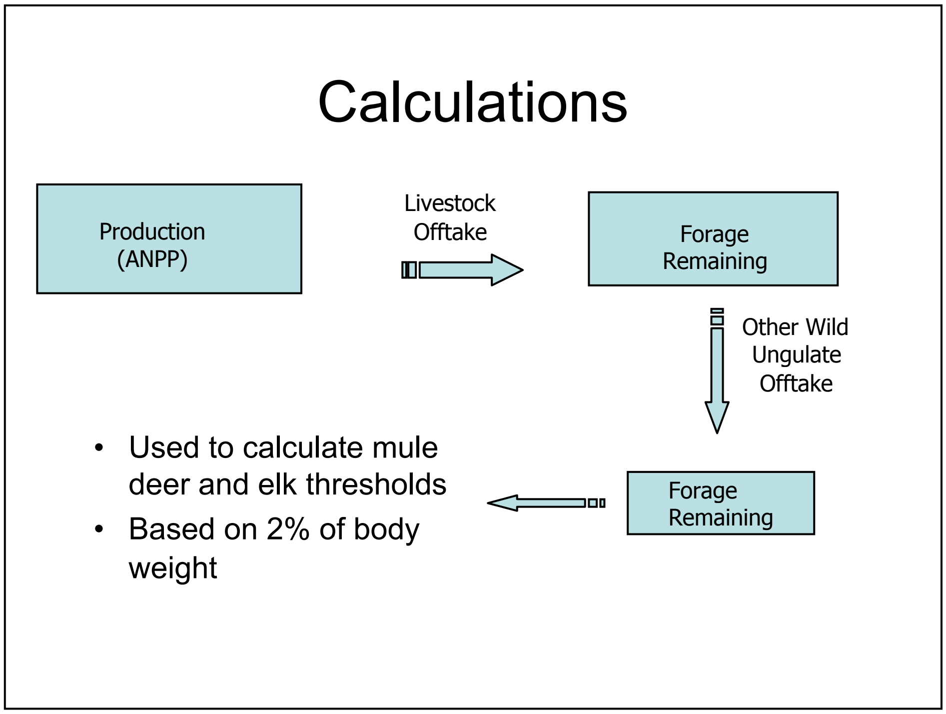

Figure 8. Logic Used to Create the Habitat Model- This simple diagram reflects the steps used in the Habitat Model to allocate available forage and predict the elk and mule deer populations that can be supported on the remaining forage base.

The previous section describes how the information relevant to each of the boxes and processes in Figure 8 is collected. The information in Figure 8 is then used in the following manner to create mule deer and elk population estimates. First, the values contained in the livestock offtake grid are subtracted from the ANPP production values for each grid cell. This step represents the removal of forage by grazing livestock. Next, the grid representing the demand from wild ungulates, other than mule deer and elk, is subtracted from the remaining forage base. The population of elk and mule deer is then based on the forage remaining in each grid cell. The Habitat Model is written with the intention that all mule deer and elk within the population predicted by the model results are allocated forage equivalent to 2 percent of their body weight per day. This ensures continued adequate performance of the projected population. The forage calculations are based on an average body weight of 150 pounds for each mule deer and 500 pounds for each elk.

V. The Use of Thresholds

A threshold represents a theoretical level at which any further stimulus will result in a response from the system. In this case, **level** refers to forage removal by grazing, while **further stimulus** equates to additional grazing pressure, and **response** represents a change in the system.

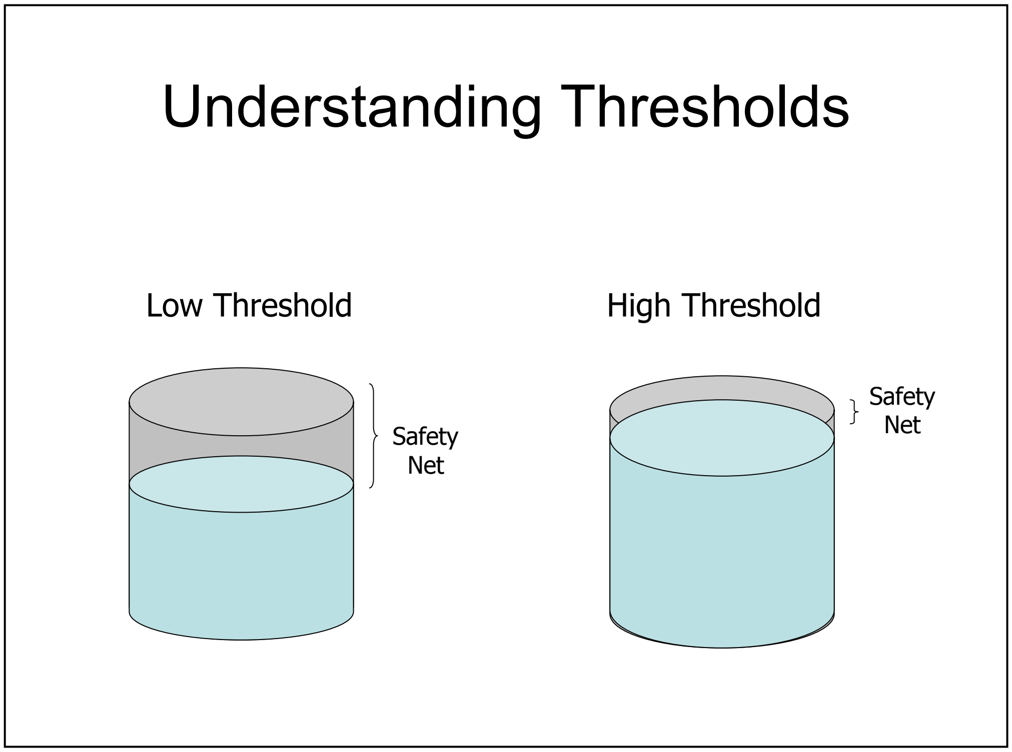

Figure 9. Understanding Thresholds- The cylinders represent the ability of the habitat to deal with stress. The light gray portion represents the stress to the system caused by the grazing the Habitat Model allows while the dark gray portion represents the remaining flexibility in the system to deal with additional stresses (climate, invasives, pests, additional

The Habitat Model calculates the forage available to mule deer and elk at a low threshold level, midpoint, and a high threshold level. Figure 9 provides a theoretical depiction of the relationship between the two threshold levels. Grazing is generally agreed to be a stressor in most systems. The low threshold represents light to moderate grazing, which should leave ample resources within the system to deal with stressors such as drought, pest infestation, or any others that may occur. This ability to deal with additional stressors is represented by the **safety net** depicted in Figure 9. The high threshold represents more intensive grazing, while theoretically, not exceeding the capacity of the system to deal with grazing stress. However, as Figure 9 shows, there is a much smaller **safety net** at the high threshold, representing a decrease in ability of the system to deal with unforeseen stressors. Both the low threshold and high threshold have their advantages and disadvantages for the habitat, and the elk and mule deer populations. An overview of these will be provided below.

A. Defining the Threshold Values

Many factors combine to determine the threshold of herbage consumption for an individual community. These factors include species composition, season of use, intensity of use and prior grazing history. The threshold levels used in the Habitat Model are based on the union of practical field knowledge and review of previous work. A number of studies have been performed to assess the effects of grazing on grassland and shrublands from various parts of the world. A review conducted by Milchunas and Lauenroth (1993) compiled 97 of these studies encompassing 276 data sets, and generated some general results for herbage consumption. In semiarid systems with a short evolutionary history of grazing, when grazed versus ungrazed plots were compared, there was a mean consumption rate of aboveground net primary production (ANPP) of 35 percent in the grazed plots. This consumption rate resulted in a moderate change in species composition from native vegetation. Holechek and Pieper (1992) show moderate grazing intensity for different semiarid range sites varies from 25 to 50 percent, with moderate grazing for sagebrush grasslands averaging between 30 and 40 percent ANPP, depending on condition.

Unlike most grazing studies that focus on the pasture or allotment scale, the threshold levels used in the Habitat Model apply to an entire landscape, and encompass numerous range-site types. For the Habitat Model, we created these numbers based on the research above and the need to distribute use across the entire landscape. The low threshold value represents the consumption of 25 percent of the total ANPP, midpoint consumption equals 28.5 percent, and the high threshold value equates to 32 percent consumption of ANPP. These thresholds are based on forage use averaged across the entire landscape. Some areas within the landscape being modeled will receive use above the threshold levels, while others will receive little or no use. The assumption within the model is that these thresholds represent sustainable usage levels based on the scale of an entire landscape. Periodic field monitoring and management actions by trained personnel will be necessary to ensure habitat sustainability in heavily used areas.

B. Low and High Thresholds Effects on Habitat

Threshold Consequences
(Habitat)

Low Threshold

- Increased ability to deal with unforeseen changes
- Habitat maintenance or improvement
- Soil protection
- May not maximize use of resources

High Threshold

- Decreased ability to deal with unforeseen changes
- Greater potential for habitat degradation
- Increased risk of soil loss
- Maximize use of resources

Figure 10. Threshold Consequences Relating to Habitat

Figure 10 provides a comparison of some of the habitat consequences related to managing at either the low or high threshold levels. At the low threshold level, a habitat has an increased ability to deal with additional stressors, and a greater chance for maintenance or improvement of habitat condition. The additional ground cover provided by the increased aboveground biomass at the low threshold level as compared to the high threshold serves to protect the soil from erosion. The greatest advantage to managing near the high threshold is that a greater portion of the forage resources within the system will be utilized.

C. Low and High Threshold Effects on Wildlife

Choosing to manage at either the low or high threshold has an impact on the performance of the elk and mule deer populations as well. Figure 11 provides a comparison.

Threshold Consequences (Wildlife)

Low Threshold	High Threshold
• Decreased intraspecific competition • More resources per individual • Higher offspring survival • More weight gain • Faster recovery from lactation	• Increased intraspecific competition • Fewer resources per individual • Decreased performance per animal

Figure 11. **Threshold Consequences Relating to Wildlife**

The low threshold provides decreased intraspecific competition resulting in more resources being available to each individual within the population. In theory and practice, this leads to increased fecundity rates, greater weight gains per individual and decreased recovery time following lactation. All of these lead to an overall healthier population. The obvious downside to operating at the low threshold is that there are fewer overall individuals within the total population. Essentially, the choice between managing at a low threshold versus a high threshold represents a tradeoff between individual performance and total number of individuals within a population.

The threshold discussion to this point has focused on comparing low threshold consequences to high threshold consequences. The low and high thresholds simply represent theoretical lower and upper limits that can be used by HPP committees to make management decisions. Population goals for trophy management are different from those promoting maximum harvest numbers. Erratic weather patterns also affect population management objectives. These thresholds only serve as guidelines. Ultimately, each committee will have to choose population levels based on their long term goals.

VI. Loading the Habitat Model

The directions that follow inform the user on the installation process for the **Habitat Assessment Model.** It is assumed the user already has some familiarity with Windows™ and ESRI Arcview™ software.

1. Create a new folder on your hard drive called **Habitat_Assessment_Model** (Be sure to include the underscores in the folder name in place of spaces).
2. Insert the Compact Disc (CD) labeled CDOW Habitat Model into your machine.
3. Copy all of the files from the CD into the folder **Habitat_Assessment_Model** that you just created.
4. Remove the CD from your computer.
5. Navigate to the **Habiat_Assessment_Model** just created and locate the **habitat.avx** file. Copy this file to C:/ESRI/AV_GIS30/ARCVIEW/EXT32.
6. This completes the file transfer process.

Activating the Habitat Extension

1. Open Arcview 3.x and begin a new project.
2. Click **File** on the toolbar and select **Extensions**.
3. Activate the **Habitat Assessment Model** extension.
4. Also activate the **Spatial Analyst** extension as shown in Figure 12.

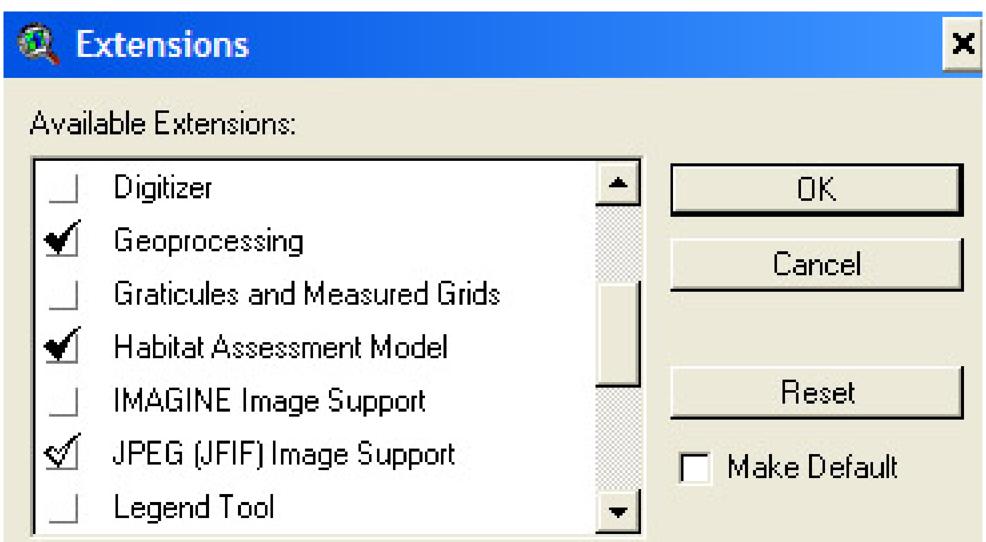

Figure 12. Arcview Extensions Window- The Habitat Assessment Model extension should now appear in the list of extensions in the Extensions window. Be sure the Spatial Analyst extension is also active while at this window.

5. Add a new view to the project.
6. Open the Add Theme Window.

7. Navigate to the directory containing all of the data copied from the CD. (This should be the **Habitat_Assessment_Model folder you created**).
8. Add all of the files that appear when "Feature Data Source" is selected as the "Data Sources Type" in the lower left corner of the **Add Theme** window.

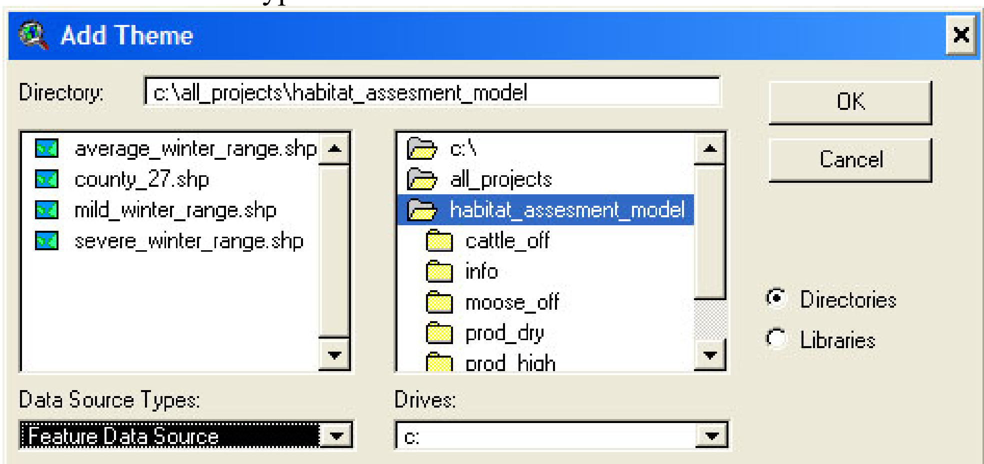

Figure 13. Arcview Add Theme Window- Be sure to add all the themes that appear as "Feature Data Source" and "Grid Data Source" while at the Add Theme Window.

9. Change the "Data Sources Type" to "Grid Data Source" and add all of these files to the view.
10. All necessary files should now be in the project to run the Habitat Assessment Model. Notice **Habitat Assessment Model** now appears on the Menu Bar at the top of the Arcview Window.

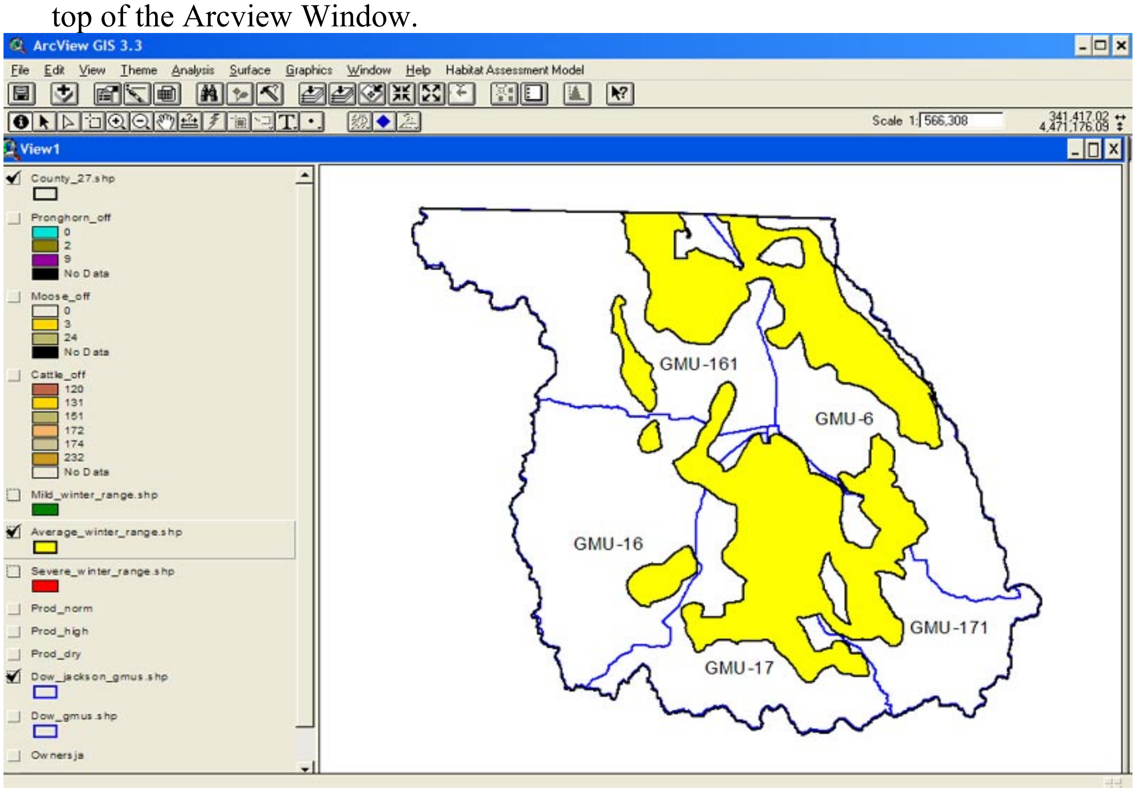

Figure 14. Arcview Toolbar with Habitat Assessment Menu Item

VII. Running the Habitat Model

After the Habitat Model has been properly installed and the Habitat Assessment Model menu item appears as a menu option, the model is ready to run.

1. To start running the Habitat Model, click the Habitat Assessment Model menu item and select "Run the Model".
2. The opening dialogue box, Figure 15, should appear displaying the model version information. Click the OK button.

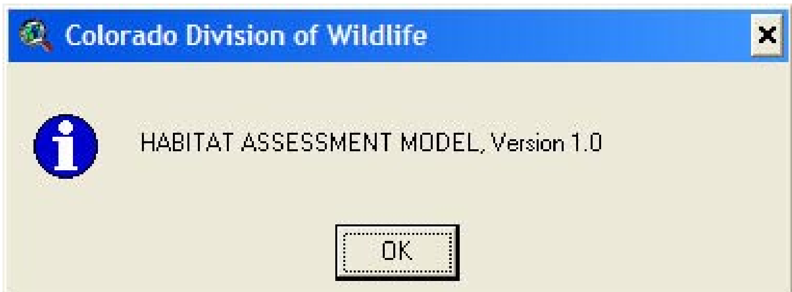

Figure 15. Habitat Assessment Model Opening Dialogue Box- This window signals the user that they have are about to run the Habitat Assessment Model. Notice this dialogue box also provides the model version information.

3. Upon clicking OK, the Prewinter Precipitation Box will appear.

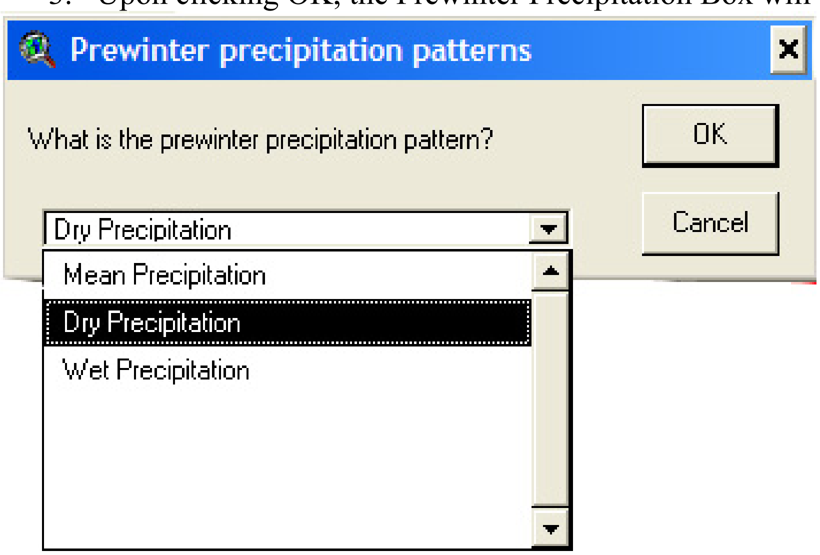

Figure 16. Prewinter Precipitation Box

The Prewinter Precipitation box provides the user with a choice of three precipitation patterns. This choice determines which of the three production values, as described in Section III, will be used for determining elk and mule deer population estimates. A dry pattern corresponds to low production, a mean pattern corresponds to average production, and a wet pattern corresponds to above average production. Refer to Section III of this manual for a review of the production value descriptions.

4. After selecting the prewinter precipitation pattern, the Winter Utilization Areas Box will open.

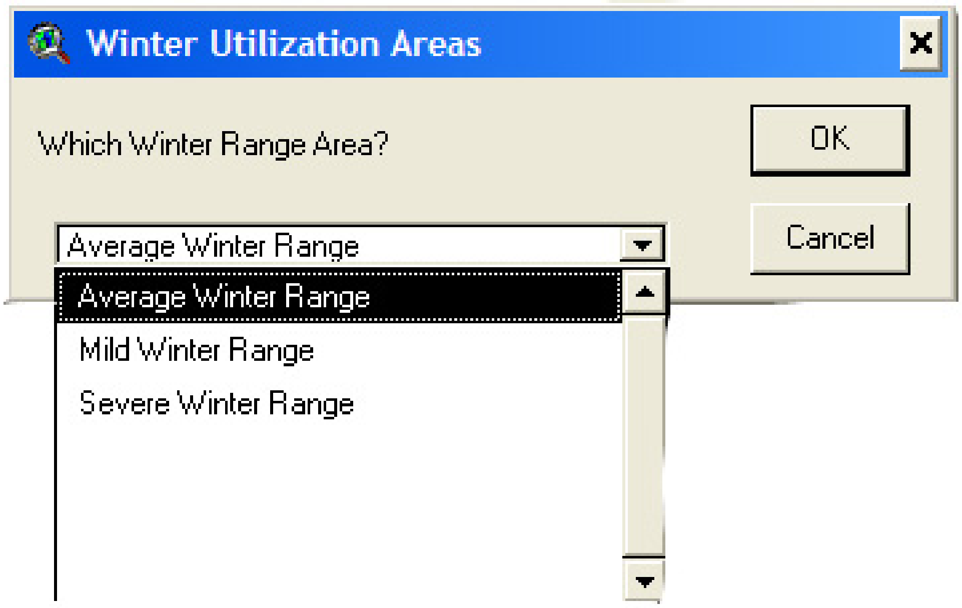

Figure 17. Winter Utilization Box- Select the appropriate winter range area.

5. The Winter Utilization Areas Box provides the user with a selection of three winter range areas for elk and mule deer populations. This selection determines which winter range area, outlined in Section III, will be used in the modeling scenario.
6. The Habitat Model will now produce an output table based on the selected criteria. Refer to Section VII for a description and interpretation of the output table results.

VIII. Interpreting the Habitat Model Results

Mean Precipitation, Average Winter Range

% Elk	Elk Low Threshold	Elk Midpoint	Elk High Threshold	Deer Low Threshold	Deer Midpoint	Deer High Threshold	% Deer
0	0	0	0	7295	21954	36612	100
10	591	1780	2969	5319	16020	26721	90
20	995	2994	4993	3980	11976	19972	80
30	1287	3874	6461	3003	9038	15074	70
40	1509	4542	7575	2264	6813	11363	60
50	1683	5066	8449	1683	5066	8449	50
60	1824	5489	9155	1215	3656	6097	40
70	1939	5835	9731	832	2503	4175	30
80	2036	6127	10217	509	1532	2554	20
90	2118	6374	10630	235	708	1180	10
100	2188	6586	10984	0	0	0	0

Figure 18. Habitat Model Results Table- This table contains predicted, sustainable population numbers for both elk and mule deer based on the input criteria selected.

Figure 18 provides an example of the table that is generated by the Habitat Model. This table contains predicted population numbers for both elk and mule deer based on the prewinter precipitation and winter range conditions selected for the model run. There are a number of key points to remember when interpreting the model output:

1. The conditions selected for the model run appear in the table title. For example, the table in Figure 18 was generated for mean precipitation and average winter range.
2. The first column (% Elk) and the last column (% Deer) of the table represent the percent of the total combined population of elk and mule deer composed by either elk or mule deer, respectively. The (% Elk) plus the (% Deer) must always equal 100 percent. Using the highlighted line in Figure 18 as an example, the combined population is composed of 70 percent elk and 30 percent mule deer.
3. The output table contains a low threshold, midpoint, and high threshold value for both elk and mule deer at all population structures. The low threshold value corresponds to consumption of 25 percent of ANPP, the midpoint equals 28.5 percent ANPP consumption, and the high threshold represents 32 percent ANPP consumption. Refer to Section V for a review of the implications associated with each threshold level. All results should be interpreted as threshold pairings. Using the highlighted example, the population at the low threshold would consist of 1,939 elk and 832 mule deer, the midpoint population would consist of 5,835 elk and 2,503 mule deer, while the high threshold totals would be 9,731 elk and 4,175 mule deer.
4. These population calculations are based on the premise that each individual within the population consumes 2 percent of their body weight in forage per day. The Habitat Model assumes each elk weighs 500 pounds and each mule deer weighs 150 pounds. Therefore, each elk is allocated 10 pounds of forage daily, and each mule deer receives 3 pounds of forage daily. Notice in Figure 18 that when the population is composed completely of elk (& Elk = 100) the low

threshold, midpoint, and high threshold values are 2,188, 6,586, and 10,984, respectively. However, when the population is 100 percent mule (% Deer = 100) there are 7,295, 21,954, and 36,612 individuals present, respectively. This difference in population values between elk and mule deer results from the difference in daily demand (10 pounds for elk, 3 pounds for mule deer), and it is important to understand the implications of this difference in the population calculations.

5. The population values presented in the output table are general guidelines. Many levels of complexity are involved in developing a model of this nature. Even though the output table provides an exact number, these values should be considered to have a margin of error +/- 20 percent.
6. Under certain model scenarios an output table may contain some zero value fields as shown in Figure 19.

Dry Precipitation, Average Winter Range

% Elk	Elk Low Threshold	Elk Midpoint	Elk High Threshold	Deer Low Threshold	Deer Midpoint	Deer High Threshold	% Deer
0	0	0	0	0	0	6760	100
10	0	0	548	0	0	4932	90
20	0	0	922	0	0	3688	80
30	0	0	1193	0	0	2783	70
40	0	0	1399	0	0	2099	60
50	0	0	1560	0	0	1560	50
60	0	0	1690	0	0	1126	40
70	0	0	1797	0	0	771	30
80	0	0	1887	0	0	472	20
90	0	0	1963	0	0	218	10
100	0	0	2028	0	0	0	0

Figure 19. Output Table Containing Zero Value Fields

These zero values under the precipitation and winter range conditions in this scenario indicate all the available forage at the low threshold and midpoint levels (removal of 25 percent and 28.5 percent AANPP, respectively) has been utilized by livestock and other wild ungulates**.** It does not mean that elk and mule are going to starve under these conditions. It means the ANPP utilization levels for the low threshold and midpoint have been exceeded by the livestock and other wild ungulate offtake. As a result, elk and mule deer will likely utilize less palatable forage and consume a greater portion of each individual plant in their foraging area. This can lead to decreases in individual animal performance and increased risk of habitat degradation.

IX. Conclusion

The Habitat Model was developed as a tool to ensure habitat sustainability while managing wild ungulate populations at the landscape level. As a cross boundary management tool, input from all responsible parties, including federal, state, and local agencies as well as local community members is critical to success. The HPP program provides a collaborative forum where the Habitat Model can be used and discussed in decisions relating to wild ungulate population management. The goal of the Habitat Model is to provide a range of population levels, and their associated risks and benefits. It is the task of the local stakeholders to set wild ungulate population numbers that meet their management objectives. However, forage availability is strongly impacted by climate. Since climatic conditions are variable, constant monitoring and evaluation is important to ensure wild ungulate population levels are in balance with habitat resources.

A primary goal of this project was to take complex ungulate-habitat interactions and include them in a GIS modeling tool that could be replicated for other areas of Colorado. In order to accomplish this goal, some assumptions and simplification of processes had to be made. As a result, the Habitat Model should only be used by individuals that have an understanding of these processes, and comprehend the complexity inherent in the model results. The results should not be taken out of the context of the Habitat Model and should only be presented when a full discussion of the Habitat Model can be included.

References:

Archer, F. and F.E. Smeins. 1991. Ecosystem-Level Processes, p.109-140. *In*: Heitschmidt, R.K. and J.W. Stuth (eds), Grazing Management: An ecological perspective. Timber Press, Inc. Portland, Oregon. USA.

Clements, F. E. 1916. Plant succession: An analysis of the development of vegetation. Carnegie Institute Publ. 242.

Cowardin, M. and M. Flenner. 2003. Colorado Division of Wildlife captures institutional knowledge using stand-up, real-time digitizing. Geoworld. 16:32-35.

Dysterhuis, E. J. 1949, Condition and management of range land based on quantitative ecology. Journal of Range Management. 2:104-115.

Heady H.F., and R. Dennis Child. 1994. Rangeland Ecology and Management. Westview Press. Boulder, CO.

Hobbs, N.T., D.L. Baker, G.D, Bear, and D.C. Brown. 1996. Ungulate Grazing in Sagebrush Grassland: Mechanisms of Resource Competition. Ecological Applications. 6:200-217.

Holechek, J.L and R.D. Pieper. 1992. Estimation of stocking rate on New Mexico rangelands. Journal of Soil and Water Conservation. 47:116-119.

Milchunas, D.G. and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs. 63:327-366.

Reed, F. Roath, L. and D. Bradford. 1999. The Grazing Response Index: A Simple and Effective Method to Evaluate Grazing Impacts. Rangelands. 21:3-6.

Wassink, J. L. 1993. Mammals of the Central Rockies. Mountain Press Publishing Company. Missoula, MT.

Weisberg, P.G., N. Thompson Hobbs, James E. Ellis and Michael B. Coughenour. 2002. An ecosystem approach to population management of ungulates. Journal of Environmental Management. 65:181-197.

Westoby, M. B., B. Walker, and I. Noy-Meir. 1989. Opportunistic management for rangelands not at equilibrium. Journal of Range Management. 42:266-274.

Yaffee, S.L., and J.M. Wondolleck. 1997. Building bridges across agency boundaries. *In* K.A. Kohm and J.F. Franklin (Eds.). Creating a forestry for the 21^{st} century: The science of ecosystem management. Pages 381-396. Island Press. Washington, D.C.

Appendix 1. North Park, Colorado Habitat Assessment Model Case Study

A. Location

The North Park Study area encompasses all of Jackson County, CO. The geography of the area includes a central, dry parkland that is bordered on three sides by mountains. The area varies in elevation from 7,798 to 12,965 meters. Annual precipitation averages 11 inches, with an annual temperature of 38 ^{o}F. Long, cold winters are punctuated by short, cool summers with a short growing season. Sagebrush grasslands on the basin floor transition to alpine communities with increases in elevation. The dominate vegetation cover by area is presented in Figure 20.

Vegetation Type	Percent Cover
Sagebrush Grassland	41
Forests	44
Irrigated Hayfields	8

Figure 20. Dominate North Park Vegetation- Percent land cover by dominate vegetation types.

The study area consists of five Division of Wildlife (DOW) Game Management Units (GMU's). They are GMU 6, GMU 16, GMU 17, GMU 161 and GMU 171 (Figure 21).

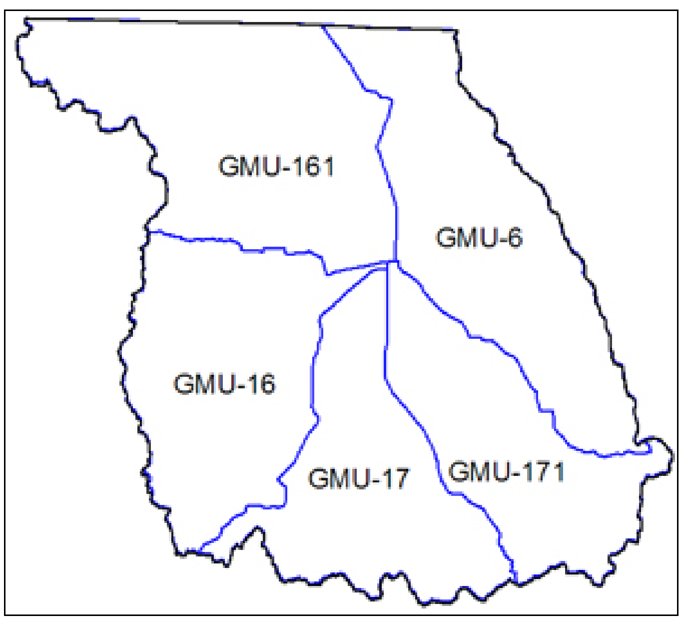

Figure 21. GMU's for the North Park Study Area

B. Project Partners

Participants involved in the project include the Habitat Model design team and the North Park Habitat Partnership Committee (HPP). The design team consists of the following personnel:

L. Roy Roath[1]- Project Lead
Gary Wockner[2]- Research Associate and Modeler
Erik Hardy[2]- Research Associate
Steve Porter[3]- HPP Coordinator and Technical Advisor
N.T. Hobbs[2]- Technical Advisor
Dave Freddy[3]- Technical Advisor

North Park HPP committee members include:

Landowner Representatives:

Danny Meyring
Blaine Evans
James Baller, Jr.

Sportsmen Representative:

Todd Peterson, Chairman

Bureau of Land Management Representative:

Dave Harr, Assistant Manager

Division of Wildlife Representative:

Kirk Snyder

US Fish & Wildlife Service Representative:

Mark Lanier

US Forest Service Representative:

Chuck Oliver, District Ranger

NRCS Representative:

Al White

Other assistance was provided by the following individuals:
Jay Widom – Colorado Division of Wildlife
Liza Graham- Colorado Division of Wildlife
Jerry Jack- Bureau of Land Management
Carol Brown

[1] Forest, Range, and Watershed Stewardship Department, Colorado State University
[2] Natural Resource Ecology Lab, Colorado State University
[3] Colorado Division of Wildlife, Fort Collins Field Office

C. Data Sources

The North Park project served as the pilot study for the Habitat Model. As the Habitat Model expands, each new area modeled will present a unique set of opportunities and challenges. The data sources listed below were the best available for the North Park study area, but each location will require a unique approach, and the methods used represent only one set of possible strategies. New methods will be necessary as the Habitat Model moves to new study areas.

1. Production Values

Prior to this project, there was no complete data set of vegetation production values for Jackson County, Colorado. As a result, production values for the North Park Study area are composed of a combination of USDA-NRCS SSURGO and STATSGO data (described in Section III of this manual) modified by field knowledge gained through previous field studies in the area. The Owl Mountain Partnership has conducted vegetation surveys in the Owl Mountain area of North Park in the years prior to the Habitat Model project. The information gained through these studies was used to modify the SSURGO and STATSGO range-site production values to better represent the current vegetation production potential for the area. Modifications were made by comparing range-site production values contained in the SSURGO and STATSGO data with information from vegetation surveys conducted by the Owl Mountain Partnership. Production value adjustments should only be made under the guidance of a range professional familiar with the study area.

2. Winter Range Polygons

Kirk Snyder and Jay Widom (North Park DWM's) met with the DOW GIS team in Walden, CO and modified the existing winter range polygons for elk, mule deer, moose and pronghorn (as described in Section III of this manual). The entire HPP committee then had the opportunity to view and change the winter range polygons using the SMART Board technology. This allowed committee members to see direct changes as a result of their feedback, creating a greater sense of data ownership for the HPP committee. This level of collaboration is necessary for a successful Habitat Model.

3. Other Wild Ungulate Offtake

Moose and pronghorn are also dominate wild ungulates in the North Park study area. Estimates of their winter population numbers were provided by the District Wildlife Manager (Kirk Snyder) for the North Park study area. From HPP committee discussion, it was determined that significant populations of pronghorn utilize the North Park study area at certain times of the year. Based on weather conditions and forage availability, some pronghorn leave the North Park study area and move to Wyoming or Middle Park. No substantial estimates of this migratory population were available, as it is highly variable. As a result, the project team and North Park committee decided to allocate forage based on estimates of the resident population that utilizes winter range forage in North Park. This decision was based on the conclusion that winter forage availability is the primary control for wild ungulate populations in North Park, and trying to accurately capture migratory pronghorn populations would not significantly enhance the Habitat Model for this area.

4. Livestock Offtake

The landowner representatives on the North Park HPP committee played a key role in providing livestock numbers and distribution for the Habitat Model. The landowner representatives are long-time residents of North Park, and are all active members of the ranching community. They estimated an annual average livestock demand of approximately 411,000 AUM's for North Park. This estimate was verified by comparison to Colorado Agricultural Statistics for Jackson County. The livestock offtake grid was created in the following manner:

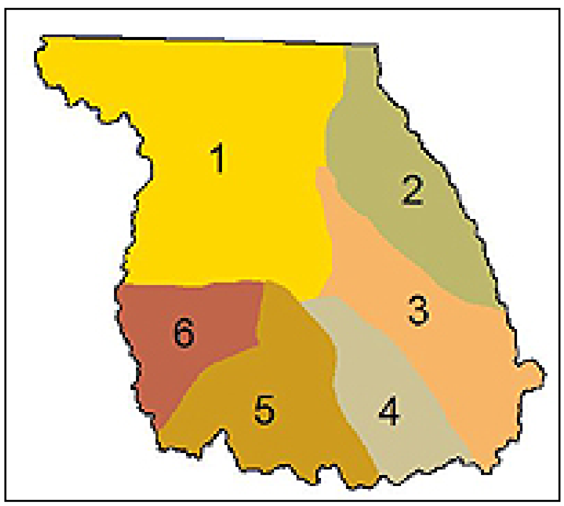

Figure 22. Cattle Offtake Regions of North Park Study Area.

1. Using their combined knowledge of livestock operations in North Park, the landowner representatives divided the study area into 6 regions (Figure 22). They estimated the number of AUM's for each livestock operation in each of the six regions. This step provided the total number of AUM's by region.

2. The livestock utilize North Park rangeland vegetation production for approximately six months of the year, with the additional demand being supplied through supplemental feeding. As a result, livestock demand on rangeland forage in each region was estimated as half the total number of

3. AUM's for that region. This produced a total demand of 205,500 AUM's for all of North Park.

4. The AUM demand for each region was then divided by the total land area of the region, creating a pounds per acre offtake value for the region (Figure 3).

5. This information was then converted into the livestock offtake grid for use in the Habitat Model.

Region	Area (Acres)	Offtake per Acre (lbs)
1	378,492	131
2	141,607	151
3	166,349	172
4	98,796	174
5	158,180	232
6	93,401	120

Figure 23. Livestock Offtake by Region for the North Park Study Area

D. Habitat Model Results

Mean Precipitation, Average Winter Range

% Elk	Elk Low Threshold	Elk Midpoint	Elk High Threshold	Deer Low Threshold	Deer Midpoint	Deer High Threshold	% Deer
0	0	0	0	7295	21954	36612	100
10	591	1780	2969	5319	16020	26721	90
20	995	2994	4993	3980	11976	19972	80
30	1287	3874	6461	3003	9038	15074	70
40	1509	4542	7575	2264	6813	11363	60
50	1683	5066	8449	1683	5066	8449	50
60	1824	5489	9155	1215	3656	6097	40
70	1939	5835	9731	832	2503	4175	30
80	2036	6127	10217	509	1532	2554	20
90	2118	6374	10630	235	708	1180	10
100	2188	6586	10984	0	0	0	0

Figure 24. Model Output for the North Park Study Area- Output for the Habitat Model under Mean Precipitation and Average Winter Range. Highlighted results for the midpoint elk and mule deer populations are near estimates of current population numbers for the study area.

Based on estimates provide by the local DWM (Kirk Snyder), there are approximately 6,500 elk and 1,500 mule deer in the North Park study area. Under conditions of mean precipitation and an average winter range, these estimates coincide with the midpoint values of the Habitat Model results (6,127 elk, 1,532 mule deer) highlighted in Figure 24. In this scenario the population is composed of 80 percent elk and 20 percent mule deer. At the low threshold level, there would be 2,036 elk and 509 mule deer, while the high threshold level allows 10,217 elk and 2,554 mule deer. There is a large range in population values between the low and high threshold levels, but this range is based on a 7 percent increase in consumption of all ANPP in the winter range area.

The Habitat Model is built on the premise that there is a finite amount of a limiting resource (forage) to support the entire ungulate population and ensure habitat sustainability in the study area. Figure 25 provides a breakdown of ANPP allocation for mean precipitation and average winter range conditions. The average ANPP per acre across the entire study area is 717 lbs/acre.

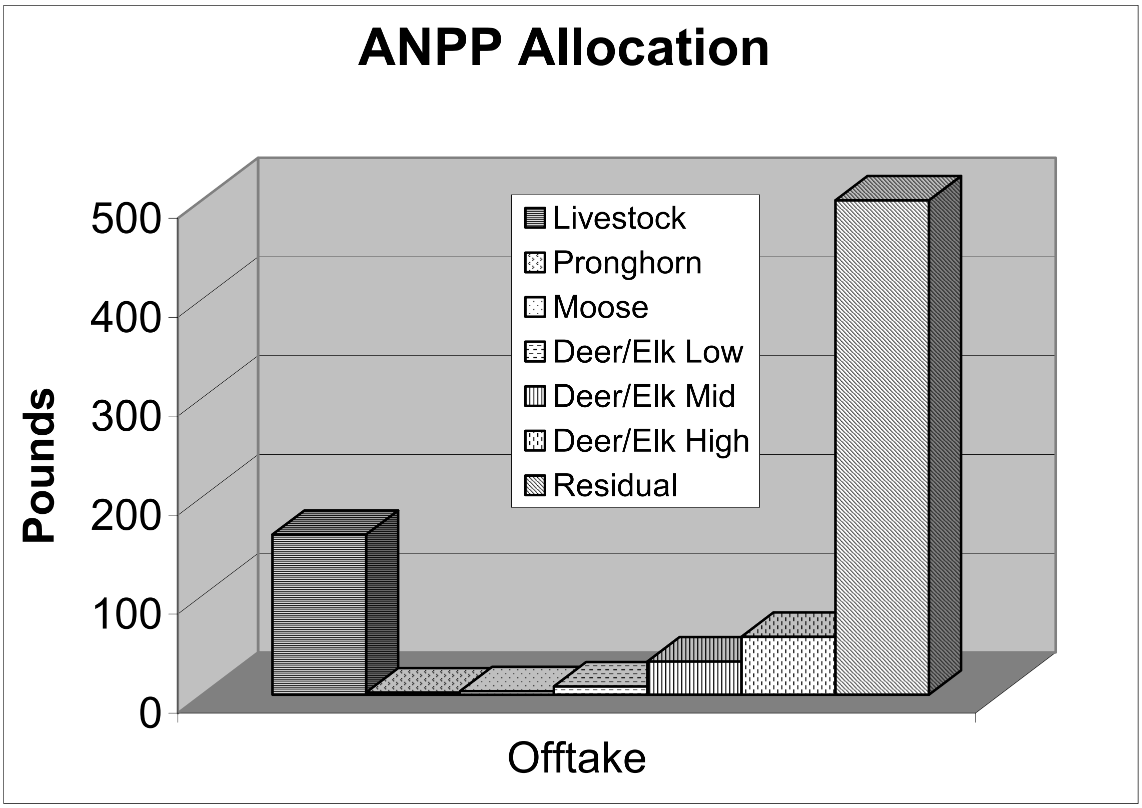

Figure 25. Forage Allocation Based on Mean Precipitation and Average Winter Range- The average ANPP per acre under these modeling conditions is 717 lbs. Deer/Elk low, mid, and high represent the low, midpoint, and high thresholds, respectively. Residual values indicate ANPP not consumed, and are between 488-538 lbs/acre depending on the threshold level used.

As shown in Figure 25, domestic livestock consume the majority of ANPP utilized by all ungulates. Mule deer and elk, even at the high threshold level, still consume significantly less than livestock, and use by moose and pronghorn is minimal. Since habitat sustainability is a key component within the Habit Model, 488 to 538 pounds of ANPP are left as residual biomass to maintain ecosystem health.

Annual variation in climate is still the major variable in controlling the amount of ANPP available from year to year in the North Park study area. A single target population is not appropriate for all conditions, as a result, it is critical to actively manage and adjust wild ungulate populations to compliment changes in forage availability.