Ecosystem Model Description

An ecosystem simulation model called SAVANNA (Coughenour 1992, 1993) was used to represent ecosystem dynamics and interactions on the PMWHR landscape. SAVANNA is a spatially explicit, process-oriented model of grassland, shrubland, savanna, and forested ecosystems. The model simulates processes at landscape through regional spatial scales over annual to decadal time scales. The model is composed of site water balance, plant biomass production, plant population dynamics, litter decomposition and nitrogen cycling, ungulate herbivory, ungulate spatial distribution, ungulate energy balance, and ungulate population dynamics submodels. The time-step of the model is one week. SAVANNA has a hierarchical spatial structure. It is spatially explicit (i.e., it is sensitive to spatial position) at the landscape scale and it is spatially inexplicit at patch scales. The landscape is typically divided 5,000-10,000 grid-cells. In the application here, grid-cell size was 500x500m.

SAVANNA is driven by monthly weather data. The model spatially interpolates precipitation data using inverse distance weighting, correcting for elevation differences between the weather station and grid-cell. The water balance submodel simulates soil moisture dynamics and use on each patch type on each grid cell. Soils map data are used, in conjunction with soil properties for each soil type, to determine soil water-holding capacities of each subarea on each grid cell. The water budget includes terms for precipitation, interception, runoff, runon, infiltration, deep drainage, bare soil evaporation, and transpiration. Soil properties were obtained from the Carbon County Soil Survey (Parker et al. 1975). Soil depth (to bedrock), field capacity, and wilting point were used to determine water-holding capacity in the model.

The net primary production (NPP) submodel simulates plant biomass flows and dynamics. Plant biomass production is affected by light, water, temperature, nitrogen, and herbivory. This submodel is explicitly linked to the water budget submodel through transpiration and plant water use. Biomass is allocated to leaves, stems, and roots. Due to water or temperature stress or phenological stage, plant tissues die and turn over at a nominal rate that reflects their maximal longevities. Plant nitrogen uptake and losses due to herbivory and tissue mortality are simulated.

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A litter decomposition and nitrogen cycling submodel simulates the breakdown of dead plant materials and animal feces. Nitrogen is released during decomposition to mineral forms that can be taken up by the plants. The decomposition and nitrogen submodel is based on the Century model (Parton et al. 1987, 1993). Nitrogen enters the system through atmospheric wet and dry deposition and biotic fixation, and leaves the system through denitrification and urine volatilization.

Animal forage intake is determined by diet selection, forage abundance, forage quality, and snow cover. Forage intake rate is expressed as a function of forage biomass. As forage biomass increases from zero to a specified level, forage intake rate increases. Forage intake rate is also affected by snow depth. Animals choose among available plant types and tissues to achieve a preferred diet composition. Diet composition is determined by using preference weightings. In this approach, diet composition is affected by the relative availability of different forage types as well as preferences or avoidances.

The ungulate energy balance submodel simulates body weight of the average animal of each species, based on differences between energy intake and energy expenditure. Energy intake depends on forage biomass intake and forage digestibility. Expenditures depend on body weight and travel patterns. The body weight of the mean animal is used to derive an animal condition index, which affects ungulate population dynamics. Metabolizable energy intake from forage consumption is the product of kg total forage intake per animal per day, the mean digestibility of the forage, the gross energy content of digestible plant matter, and metabolizability.

The ungulate population dynamics submodel represents changes in the number of animals in each age classes, for each sex. Birth and death rates are affected by animal condition indices. As condition index increases, birth rates increase and death rates decline. If animals are in poor condition, an additional death rate is added to the nominal death rate due to aging. The effects of condition index represent population responses to ecological conditions governing forage availability (e.g., forage production, snow depth) and intra- and interspecific competition. Competing animals can reduce forage supply, forage intake rate, and thus body condition and population growth rate of their competitors..

The ungulate spatial distribution submodel dynamically simulates animal distributions over the simulated landscape or region on a weekly basis. The suitability of habitat in a grid-cell is affected by functions of slope, temperature, forage biomass, forage intake rate, snow depth, distance to water, shrub, and tree cover. The effect of physical landscape features is computed as the minimum of the effects of slope, elevation, and and tree cover.

Model Parameterization

Six functional groups of plants were simulated: grasses, forbs, shrubs, mountain mahogany (*Cercocarpus*), juniper, and coniferous trees. These groups were chosen to meet the objectives of this modeling analysis, without making the model overly complex. Grasses and forbs represent the herb layer, and are different with respect to morphology, photosynthesis rates, root:shoot allocation, leaf nitrogen concentration, phenology, and ungulate dietary preference. Dietary data indicate a relatively low amount of forbs in horse diets (Kissel 1996) relative to their abundance (Gerhardt and Detling 1998).

A vegetation map for BCNRA was developed by Knight et al. (1987), but none existed for the remainder of the PMWHR. I developed a PMWHR vegetation map by merging the BCNRA vegetation map with a modeled vegetation map for the remaining area. The modeled vegetation map was based on a map of forest cover, from USGS quad sheets, the soils map, and qualitative relationships between major vegetation types, elevation, and soils observed on the Knight et al. (1987) map.

It has been established that there are three relatively distinct herds of horses in the PMWHR, occupying habitats that are separated by distinct topographic barriers (Hall 1972; US

BLM 1984, 1997; Singer et al. 1998).Each of the three herds was modeled separately and distributions were limited to their respective range areas. Seasonal movements were modeled as dynamic responses to changing forage and snow conditions, with a seasonal avoidance of areas below 1,500 m in summer

In simulations using observed population data, the summarized horse data from USDI/BLM (1997) were used, based on data from Taylor (1990 memo), and Garrott and Taylor (1990). Sheep population data were obtained from Coates and Schemnitz (1989) and Kissell et al. (1996). Mule deer population size was 600 animals in 1992, 800 in 1993-1994, and 125 in 1996 (Kissell 1996). Due to a lack of data, the deer population was set at 600 prior to 1992. Horse culling data from BLM (1997) were used in simulations using observed culling data. Deer were culled according to a rule that maintained the population between 500 and 700. Bighorn sheep have never been culled or hunted.

The locations of known watering points within the horse range were digitized from information provided by the BLM (L. Padden, BLM, personal communication). Only watering points located within the horse range were considered. These include: three permanent springs, water piped from a spring on the Sorenson Extension; two artificial catchments; two reservoirs on top of the mountain; and an access point to Crooked Creek. A map of distance to water was calculated using the GIS

Bighorn sheep were kept within the seasonal ranges observed by Irby et al. (1994). Within these ranges, the model redistributed animals in relation to forage biomass and forage energy intake rate. Mule deer winter on the PMWHR, but during summer, most migrate to ranges north of the PMWHR (Irby et al. 1996). The model was parameterized so that the entire deer herd was on the PMWHR during December-April, and 10% were on the PMWHR during June-October.

Data from Detling and Gerhardt (1996) were used to parameterize the plant growth model, and test its predictions. The objective was to maximize the model's skill in providing realistic simulations, by making maximal use of information contained in the field data and literature. Root biomass was estimated by fitting model aboveground predictions to the aboveground data. Biomass dynamics on plots inside grazing exclosures were verified first, followed by the dynamics of grazed plots. Grazing intensities in the grazed simulations were estimated by varying horse density to best simulate observed differences between exclosed and grazed plant biomass dynamics.