ECOSYSTEM MODELING OF THE PRYOR MOUNTAIN WILD HORSE RANGE

Executive Summary

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INTRODUCTION

The US Bureau of Land Management (BLM) is responsible for the maintenance of a "thriving ecological balance" on the Pryor Mountain Wild Horse Range (PMWHR) and has deemed it necessary to conduct periodic management removals of wild horses since 1970 to halt and prevent range degradation (USBLM 1997). The PMWHR includes lands which are administered by the National Park Service (NPS), specifically, portions of the Bighorn Canyon National Recreation Area (BCNRA), as well as lands administered by the BLM and the U.S. Forest Service (Hall 1972; US BLM 1984) . It has been federally mandated that wild horses have access to the NPS lands, by inclusion of the BCNRA in the designated PMWHR. However, in setting the appropriate numbers of wild horses, other NPS management objectives must be weighed, including protection of native plant communities and wildlife. In the past, horse carrying capacities have been calculated using a widely accepted method that sums up total forage biomass, applies a proper use factor of 50% utilization. The appropriate number of horses on the PMWHR must be explained in terms of measurable and predictable changes brought about by different horse densities in the abundance and composition of soils, plants and wildlife, and in the condition and welfare of the horses. These responses depend on plant species, the levels and patterns of herbivory, climate, soil properties, and their distributions on the landscape. Forage varies annually, and spatially over the landscape. Horse distributions vary seasonally, and parts of the landscape are used more heavily than others. Although it is unlikely that these wild horses will ever be allowed to self-regulate, there is a need to estimate the results if that were to occur. A general approach is necessary, which can assess the effects of herbivory on soils, plants, and animals in a dynamic and spatially heterogenous landscape. Here, a neutral, ecosystem modeling approach was used, which makes no specific assumptions about management objectives, levels of proper use, ideal range conditions, or equilibrial biotic communities.

The objectives of this study (Coughenour 1999) were to: (a) evaluate a general, ecosystem modeling approach to support more informed policies for managing large ungulates; and (b) assess the effects of different numbers of horses on ecosystem structure and function on the PMWHR. This is an alternative approach than traditional approaches to evaluating carrying capacity based solely on forage supply or animal population dynamics.

METHODS

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 is a spatially explicit model (i.e., it is sensitive to spatial position). Typically, the landscape is typically divided 5,000-10,000 grid-cells. The model simulates water and nutrient balance, plant growth, and herbivory on each grid-cell. 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.

The net primary production (NPP) submodel simulates plant biomass production 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. The model represents plant nitrogen uptake and losses due to herbivory and tissue mortality.
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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. 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 affected by the relative availability of different forage types as well as preferences or avoidances.

The animal 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 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. This is the way the model represents population responses to factors affecting forage availability, including plant growth rates, and snow depth, and forage removal by other animals.

The ungulate spatial distribution submodel simulates animal distributions over the simulated landscape or region on a weekly basis. Habitat suitability is affected by slope, temperature, forage biomass, forage intake rate, snow depth, distance to water, and tree cover.

Model Parameterization

Six 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.

A vegetation map existed for BCNRA (Knight et al. 1987), but none existed for the remainder of the PMWHR. Consequently, 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.

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
The locations of known horse watering points within the horse range were digitized from information provided by BLM personnel (L. Padden, BLM, personal communication). 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.

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 based on information from Kissell (1996). Horse culling data from the BLM (1997) were used in simulations using observed culling data. Deer were culled to maintain the population between 500 and 700. Bighorn sheep have never been culled or hunted.

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.

RESULTS

Model Tests

The model performed well in simulating herbaceous plant growth with and without grazing. The model successfully simulated herbaceous biomass dynamics across a wide range of sites and weather years. The proportions of grasses and forbs, rates of transfers from live to dead, and rates of transfers of dead tissues to soil were adequately simulated. The model simulated reasonable population dynamics and distributions of horses, bighorn sheep, and mule deer. The rates of forage offtake per animal, and the compositions of the herbivore’s diets were realistic. Overall, the model provided estimates of plant production and animal behavior that were consistent with available data.

Dynamics

A simulation was run with horse numbers held at 270 animals (the number first counted by Feist and McCullough [1975]) during the period from 1950-1969. The model simulated markedly reduced herbaceous biomass compared to no horses. Forb biomass comprised a greater proportion of total peak standing crop, while grasses comprised a smaller proportion, compared to no horses. Root biomass was also diminished. Total aboveground plant growth, including transfers to dead and litter, decreased under grazing. In another simulation, horse populations were allowed to grow freely, to limits imposed by the environment. Plant responses were not markedly different from those observed with a fixed number (270) of horses. Horse numbers initially increased, leveled off at around 400, and then plunged dramatically in 1960-1961 in response to a drought in 1960. Thereafter, horse numbers gradually increased to 270.

In simulations of the period from 1970-1996 without horses, grass biomass generally increased over time. Forb biomass increased less, so the proportion of forbs in total herbaceous biomass decreased. With observed horse numbers over this period, grass biomass varied from year to year, but there was no long-term trend. The ratio of grass to forbs was similar throughout. When horses were not culled, biomass of grasses decreased over time.

With no grazing, root biomass of grasses fluctuated, but there was no trend. Grass roots eventually became more abundant than forb roots. With observed animal numbers, grass and forb roots varied within a range that was slightly less that with no animals, and there was no long-term trend. With no culling, root biomasses of both plant groups were lower and decreased over time Herbaceous basal cover increased during the first 15 years of simulations with no animals. Grass and forb cover increased when grazed with observed animal numbers, but then leveled off at lower levels than with no animals. Grass and forb cover increased when grazed with observed animal numbers, but then leveled off at lower levels than with no animals.

Forage intake rate for horses varied seasonally and annually. Generally, most stressful years for forage intake were also years with deeper snow depths. Maximum intake rates for the Dryhead head were consistently lower than for the other two herds, as a result of the lower forage biomass on the Dryhead summer range. Intake rates were markedly reduced when horse herds were not culled. Maxima and minima were both reduced at higher horse densities, as a consequence of intraspecific competition for forage. Sheep intake rates were far less variable than horse intake rates, primarily because they could shift to browse species which continued to be abundant during the winter and were not used by horses.

Spatial Distributions

Maps of simulated total aboveground net primary production (ANPP, ie. total aboveground plant growth) with and without horses were similar, but there were certain areas where production was diminished with horse grazing. These included the area just south of the Sorenson Extension boundary, and areas in the south-central portions of the Sykes and Burnt Timber Ridge horse ranges. With observed horse numbers, grass ANPP was 60-80% lower in some areas than without horses. With no horse culling, there were areas where grass ANPP was reduced by 80-90% and forb ANPP was reduced by 50-70%. With observed numbers of horses, roots decreased by 25-75% in some areas, but these areas constituted a small fraction of the landscape. With no horse culling, areas of decreases rose to 50-90%, and a larger fraction of the landscape showed decreases in the 25-50% range.

Horse grazing shifted species composition towards a greater preponderance of forbs in most places, but the shifts were differentially distributed across the landscape. There was a greater species shift at the higher elevations, with forb proportions increasing to 40-70% at some high elevation areas. Litter and shoot biomass reductions cause an increase in bareground, with potential secondary effects on soil temperature, runoff, and soil erosion.

With the observed numbers of horses, grass herbivory levels reached 70-80% over significant portions of the landscape. However, much of the landscape was lightly (<20%) or moderately (20-60%) grazed. Grasses on the southern parts of the Sykes Ridge and Burnt Timber Ridge, and northern part of the Dryhead Range were heavily (>60%) or very heavily (>80%) grazed. Grazing intensity on the high elevation summer range was mostly moderate, High rates of grass offtake were far more prevalent when there was no horse culling. Grasses on 30% of the landscape were grazed in excess of 50%. Grasses on 8% of the landscape were utilized >90%.

Horse densities were heterogeneously distributed on the landscape. With observed horse numbers, highest use areas at low elevations were 2-5 head per km^2 year-long. Heavy use areas at the top of the mountain were higher, reaching 6-8 head per km^2 year-long. When horses were not culled, densities reached higher levels everywhere, with low elevation high use areas reaching 5-8 head per km^2 and high elevation high use areas reaching 7-10 head per km^2 year-long.

The fraction of the landscape receiving >80% herbivory varied markedly from year to year. During 1970-1996, 37-67% of the landscape received light (0-10%) herbivory with observed horse numbers and 13-38% received 10-50% herbivory. However, 3-14% experienced herbivory in the 50-80% range and 2-31% received >80% herbivory.

With no horse culling, the fraction of the landscape where grasses were grazed >80% rose to 21-44%. The fraction grazed 50-80% was 3-13 % with 100-150 head, 4-13% with 150-200 head, and 4-14% with 200-250 head, and 3-15% with no culling. The fraction where grasses were grazed >80% was 8-31% with 100-150 head, 12-34% with 150-200 head, 16-34% with 200-250 head, and 21-45% with no culling.

As horse numbers were increased, herbaceous ANPP on the primary horse range decreased by 10-13% for each additional 50 horses. There was approximately 75% as much herbaceous production with 200 horses as with 50 horses. With 350 horses, ANPP was about 60% of that with 50 horses. There was 60% as much herbaceous biomass with 200 horses as there was with 50 horses. With 350 horses there was <50% as much biomass as with 50 horses.

The effects of disallowing trespass use of USFS lands northeast of PMWHR was examined by running the model for the period 1970-1996 at seven different horse densities. There was a slight reduction in plant growth with no access to USFS lands compared to full access. The proportion of forbs was similar with or without USFS access, but there was a slight increase in forbs without USFS access. A similar response was simulated for root biomass. Horse condition was also slightly lower when USFS access was disallowed. Differences between runs with and without USFS access were neglible with less than 150 horses, but increased at higher numbers of horses.

Interactions with Bighorn Sheep

Neither sheep condition index nor sheep forage intake rate were affected by increasing horse numbers. One reason for this appeared to be a high degree of spatial segregation, where sheep ranges overlapped onto a small fraction of the total horse range. A second reason was dietary separation. A significant fraction of sheep diets were from evergreen shrubs, which were an insignificant component of horse diets (Kissel 1997). Finally, sheep appeared to be strongly influenced by their own density within their own range.

Increasing numbers of sheep had very little impact on horse condition or horse forage intake, but did have a substantial effect on sheep condition and sheep forage intake rate. This suggests that there was a considerable degree of intraspecific competition for food within the prescribed sheep range. As sheep depleted forage within their prescribed range, horses had substantial options for foraging elsewhere.

In simulations using stochastic weather, horse numbers fluctuated within the ranges specified by culling targets at the 100-150 and 150-200 levels. When culling to 200-250, however, there was a drop in population sizes below the 200 level, as a result of horse interactions with vegetation and climate. When horses were not culled at all, there was marked variation among horse population trajectories. Horses reached at most 350 in the stochastic runs without culling. When horses were culled, or not present, the final median number of sheep was about 175, irrespective of horse numbers. When horses were not culled, the final median number of sheep was about 160.

Comparisons to Previous Analyses

Model predictions of forage biomass agreed with the actual forage productivity estimates used in the BLM's 1984 carrying capacity assessment, but not with the 1984 potential productivity estimates. The model agreed reasonably well with the potential productivity estimates of the BLM's 1992 carrying capacity assessment, but not with the 1992 actual productivity estimates.

It was difficult to make an exact comparison between the traditional range site-based carrying capacity estimates and the estimates of appropriate horse numbers using the ecosystem modeling approach, since the two methods measure carrying capacity differently. The ecosystem approach demonstrated that the proper use factor of 50% used in the range site approach is exceeded on portions of the landscape, even with 100 horses. Averaged over the entire landscape, offtake is actually much less than 50%, even with as many as 200 horses. The simple proper use factor is of limited utility when grazing is so heterogeneously distributed.

CONCLUSIONS

1. The model responded realistically to climate, soil properties, grazing, and their interactions. Model predictions were consistent with current knowledge about the underlying processes of ecosystem water and nutrient budgets, plant and animal ecophysiology, and animal population dynamics.

2. Horses increased to over 300 in many weather scenarios, and even to >450, if they were not culled. This could be regarded as the ecological carrying capacity of the population. The rate of increase of the simulated population was as observed, under the observed levels of forage availability per animal. It can be inferred from model results and other data that the horses have a capacity to increase to high densities relative to forage resource, and persist in environments with relatively low forage biomass. In other words at ecological carrying capacity, horse numbers would be relatively high and plant biomass would be relatively low. The result is consistent with other studies which indicate that in natural grazing ecosystems, native equids tend to be predator rather that food limited.

3. As horse numbers increased, total forage production on the primary horse range decreased by 10-13% for each additional 50 horses. On average, there was approximately 75% as much forage production with 200 horses as with 50 horses.

4. Grazers decreased aboveground biomass, as expected . Model simulations and data indicated that most of the reduction was in standing dead rather than in live biomass. In the absence of grazing, dead biomass was more likely to accumulate.

5. The model simulated an increase in the relative abundance of forbs compared to grasses as herbivory pressure increased. There is only weak support for such a species shift in the data. However, changes in forb composition would be expected based on the lower relative abundances of forbs than grass in animal diets.

6. Basal cover and root biomass decreased under increased herbivory due decreases in above and belowground primary production relative to root turnover. This was consistent with the generally accepted theory that forage productive potential varies with range condition.

7. The model agreed reasonably well with the actual forage productivity estimates used in the BLM's 1984 carrying capacity assessment and with the potential productivity estimates of the BLM's 1992 assessment. However, there were discrepancies between the model and the 1984 potential productivity estimates (if range were in excellent condition), and between the model and the 1992 actual productivity estimates. These discrepancies suggested that there is uncertainty associated with previous estimates of maximum forage production and range condition.

8. The proper use factor of 50% that is used in the range site approach is exceeded on portions of the landscape, even with 100 horses. Averaged over the entire landscape, however, offtake is actually much less than 50%.

9. Grazing was heterogeneously distributed. With observed horse numbers, highest use areas at low elevations were 2-5 head per km^2 year-long. Heavy use areas at the top of the mountain were higher, reaching 6-8 head per km^2 year-long. During 1970-1996 with observed horse numbers, 40-70% of the landscape experienced light herbivory of grasses. However, 5-20% received >80% herbivory and 5-15% experienced herbivory in the 50-80% range. The fraction of the landscape receiving >80% herbivory varied markedly from year to year.

10. The percent of the landscape where grasses were grazed in excess of 80% increased from 16% at 125 horses to 25% at 225 horses, however in a given year the maximum percentage varied from 31% with 125 horses to 36% at 225 horses. The mean proportion of herbaceous plant growth consumed on the entire landscape varied from a mean of 15% at 125 horses to a mean of 23% at 225 horses.

11. A simple proper use factor is of limited utility when grazing is heterogeneously distributed.

Instead, a proper use factor must be two-tiered, specifying both the spatial stratification of grazing intensities, and the acceptable grazing pressure within strata. For example, proper use could be specified as a maximum acceptable fraction of the landscape that is grazed in excess of 80%. Alternatively, a proper level of use should be applied to key areas of the landscape which typically most heavily grazed. It would be useful to reach a consensus about the level of acceptable use in these terms, which are more realistic than a simple proper use factor.

12. Horses had little effect on bighorn sheep populations due to a high degree of spatial segregation, dietary separation, and the fact that sheep are strongly influenced by their own density within their own range. Sheep ranges overlapped onto a small fraction of the total horse range. This result should be interpreted with caution since potential sheep habitat that is still unoccupied may be affected differently by horses. There is a need to assess potential horse-sheep interactions throughout the potential sheep range.

13. A GIS model of sheep habitat appeared to be too restrictive in the PMWHR, probably because it did not consider the effects of low forage availability, and the need for sheep to forage further from escape terrain. Although the GIS-based approach could be modified to incorporate effects of forage production and snow, an alternative, and probably better approach is to implement a less restrictive GIS habitat model in a spatial simulation model of forage production and snow cover, as was done here.

14. Continuous rather than threshold responses to increasing horse made the task of deciding upon an appropriate number of horses difficult. The analysis showed no optimal number of horses, as in a peak level of performance of ecosystem processes. With as few as 50 horses, there was some decrement of plant growth. Given this, the optimum number of horses may be the minimum number needed to safely ensure the population and genetic viabilities of the horses. This number would minimize decrements to vegetation productivity, while ensuring continued viability of the horse herd.

15. It would be desirable to spread out horse grazing impact so that the fraction of the landscape receiving heavy use is reduced. To achieve a more uniform distribution of percent offtake, it would be necessary to distribute horses in proportion to plant production, which varies markedly across the landscape.

16. At ecological carrying capacity, plant cover would be considerably lower than it is now. The range would appear to be extremely heavily utilized as grass offtake would climb to over 90% in many more areas. Some areas would be nearly barren. Herbaceous biomass above and belowground would be reduced to less than 20% of potential in many areas. There would probably be secondary effects on wildlife. With greater exposure due to reduced plant and litter cover, soil erosion rates would likely be higher than at present. Horses would be in generally lower condition. Total annual horse mortality would be high, due to a larger total number of horses would be higher, and the fact that annual births would have to be balanced by deaths. Thus, to meet range management and animal welfare objectives, the population must be managed below its ecological carrying capacity.

17. The effects of curtailing recent horse trespass onto USFS lands northwest of the PMWHR boundary on forage production and horse energy balance would be negligible.

18. As part of an adaptive management process, the model should be revisited periodically, to check the consistency of it's predictions with actual results. Ecosystem monitoring should be designed to test some of the key model predictions. The model should then be revised and a new assessment should be carried out.

19. Better data are needed for estimating plant production in the long-term absence of grazing. It would be best to monitor biomass at the 4 long-term exclosure sites and the 12 additional exclosure sites that were established in 1992 and 1994.

20. The combination of field research and ecosystem modeling that has been carried out in the PMWHR is an example for improving the scientific management and conservation of wild equids on rangelands in the western United States and other regions of the world.