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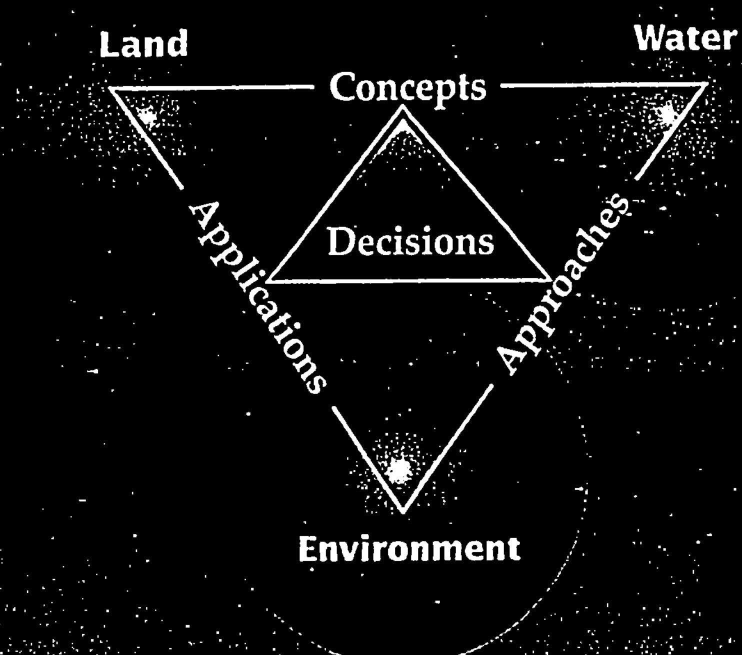

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Chapter 31

Evaluation of a Prototype Decision Support System for Rangelands in the Southwest United States

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Abstract

The appearance of rangelands in parts of the southwestern U.S. is changing from grasslands with scattered shrubs to sparse grass populations under dense stands of mature woody shrubs, mostly of mesquite (*Prosopis velutina*). Decisions on whether to control the mesquite, coupled with a variety of grazing systems, make it appropriate to use decision support systems (DSS) as an advisory tool. This paper presents a preliminary evaluation of grazing and vegetation management systems for rangelands using a prototype multiobjective DSS (P-MODSS) developed by the USDA Agricultural Research Service at the Southwest Watershed Research Center in Tucson, Arizona. Sixteen years of measured and calculated data from four experimental watersheds were used to quantify physical resource decision variables of runoff depth, sediment yield, aboveground net primary production (ANPP), and peak rate of runoff. The results suggested that when it was desirable to maximize ANPP and minimize runoff and sediment yield, yearlong grazing with mesquite removed was preferred to the conventional system of yearlong grazing with mesquite retained and rotation grazing with and without mesquite. However, when both runoff and ANPP were maximized and sediment yield was the most important criteria, no alternative was better than the conventional system. The

importance order of the decision variables and the scoring function shape are highlighted to demonstrate the utility of the P-MODSS to evaluate management systems on rangelands.

Introduction

Rangelands cover a large portion of the land surface of the world. Depending on the definition of rangelands, 25 to 50% of the earth's land is used as rangelands (van Gils, 1984). Characteristics that link rangeland ecosystems worldwide include a complex biology, large and heterogeneous management units, variable climate, and socioeconomic pressures for change or modifications (Stuth and Stafford Smith, 1993). These special features of rangeland management necessitate that a broad perspective be taken in the planning process and that information be well organized.

While the major commercial use of rangelands in the U.S. is livestock grazing to produce food and fiber, rangelands provide other less tangible values such as natural beauty, open spaces, wildlife habitat, and the ecological study of natural ecosystems (National Research Council, 1994). If rangelands are to be sustainable, methodologies are needed to facilitate informed decision making. Such methodologies should consider the whole system rather than concentrate on individual components. DSS provide a means of integrating databases, computer simulator models, economic analyses, and geographical information systems in a package that is practical and informative to the land use planner. In addition, the DSS needs to fulfil user requirements, be technically correct, consider diverse objectives, and present the user with information on feasible alternatives to the current grazing system.

This paper presents preliminary results of the application of the P-MODSS developed by the USDA Agricultural Research Service, Southwest Watershed Research Center, in Tucson, Arizona, to evaluate four current and alternative rangeland management practices in southwestern U.S. Specifically, the work demonstrates the effects of an importance order on the outcomes from the DSS for four decision criteria. The P-MODSS (Yakowitz et al., 1992a,b) was originally developed to assess the effects of alternative management practices on surface and groundwater quality. Use of the P-MODSS to evaluate farming practices in cropping lands (Yakowitz et al., 1992a; Yakowitz et al., 1993; Heilman, 1995) and the design of trench caps for shallow landfill waste (Lane et al., 1991; Paige et al., 1994) are well established, however it is only recently that the application to rangelands has been examined (Renard and Stone, 1993). Although the P-MODSS has the capacity to incorporate continuous simulation models, the analyses reported in this paper were restricted to using measured data from four instrumented watersheds on the Santa Rita Experimental Range to quantify the decision variables.

Background to the Problem

Increases in velvet mesquite (*Prosopis velutina* Woot.) have changed the general appearance of much of southern Arizona from grasslands with scattered young mesquite to sparse grass populations under dense stands of mature woody shrubs (Parker and Martin, 1952; Cable and Martin, 1973). When the mesquite is controlled, herbaceous cover and production have increased (Parker and Martin, 1952; Martin, 1963) while soil loss and runoff have declined (Renard et al., 1991; Martin and Morton, 1993). Methods to control the invasion of mesquite include mechanical or chemical means, burning, or a combination of each. However, costs to control the mesquite may not be economically justified from the net returns of the cattle alone. In addition, increased awareness of wider, socioeconomic aspects of desert grasslands and recognition of the continued degradation of natural resources have engendered an ecological perspective into vegetation management.

In addition, grazing management is linked to vegetation management. Options for grazing are continuous yearlong or a system of seasonal grazing that employs one or more types of grazing and nongrazing periods. The intended benefit of rotational grazing systems is improved range condition. Although rotational grazing has lead to increased grass production (Martin, 1973), these have not necessarily transferred to positive livestock responses (Driscoll, 1967) despite the increased input of management. While many studies have focused on the health of the plant and animal, there is a need to consider the effects of grazing from the perspective of soil, water, and air quality. To this end, some grazing practices may create an unsustained and unbalanced structure between the abiotic and biotic components of the ecological system.

Methods

Description of Watersheds and Data Collected

Eight experimental watersheds were established by the USDA Agricultural Research Service during 1975 on the Santa Rita Experimental Range, located 50 km south of Tucson, Arizona. The purpose of the watershed study was to examine the impact of grazing and vegetation manipulation methods in the semidesert (300 to 400 mm annual precipitation) regions of the southwestern U.S. Four of these watersheds were selected for this analysis. One pair of watersheds were grazed yearlong, while the other pair of watersheds were grazed using the Santa Rita rotation method (Martin, 1978). This method involved grazing once during March to October and once during November to February in a 3-year rotation, with 12-months rest between grazing periods. The dominant feature of the method is that rangeland to be grazed in the spring is rested during the preceding summer and winter and is an important component for proper grazing management in this environment (Arizona Interagency Range Committee, 1973). In 1974, two watersheds (WS2 and WS4) were treated with basal applications of diesel oil to control the invasion of mesquite and retreated when needed to keep the watersheds mesquite free. The other two (WS1 and WS3) remained unchanged. In 1994, the aerial coverage of mesquite and dense woody shrubs in WS1 and WS3 was 17 and 22%, respectively. Treatments and physical characteristics of the watersheds are given in Table 31.1.

Each watershed is equipped to measure precipitation (rate and depth), surface runoff (rate and depth), and sediment yield. On the occasions when there were insufficient sediment samples, sediment yield for the storm event was estimated

Table 31.1 Summary of Physical Characteristics of the Experimental Watersheds

WS	Area (ha)	Land Use Treatment		Soil type	Average (%)	Stream (m)
		Grazing	Vegetation			
1	1.63	Yearlong	Mesquite +	Sandy	3.43	329
2	1.76	Yearlong	Grass	Sandy	4.21	256
3	2.76	Rotation	Mesquite +	Fine sandy	3.01	298
4	1.97	Rotation	Grass	Fine sandy	4.01	306

using the measured depth and peak rate of runoff. The precipitation and runoff data are considered to be excellent (Renard et al., 1991). Periodic measurements were also made of channel cross-sections, grass density, and cover.

Summary of Hydrological Responses

Precipitation at the Santa Rita watershed study varies considerably from year to year, and from season to season. From 1976 to 1991, annual precipitation varied from 177 to 641 mm. Mean annual precipitation across the four watersheds was 373 mm, with a coefficient of variation of 29%. The bimodal distribution of monthly precipitation for WS1 is shown in Figure 31.1. Surface runoff is generated by short-duration, high-intensity summer storms. Between June and August, runoff producing storms represented 26% of the annual precipitation, but produced 66% of the total annual runoff. The temporal and spatial variability of storms in the Southwest has important implications for range management (Renard and Stone, 1993). For example, when spatial variability is high, summing storm events from a single raingauge to determine monthly or seasonal precipitation for water supply and forage management may unknowingly be misleading. In addition, partial wetting of the pasture will generate heterogeneous growth that may influence the degree of pasture utilization, and possibly species vigor and composition.

In this environment, essentially all the infiltrated moisture is partitioned as either bare soil evaporation or transpired by plants (Renard et al., 1993). Percolation below the root zone is infrequent and represents a negligible component in the average annual water balance.

Overview of the P-MODSS

The major components of the P-MODSS are (1) a modified version of the GLEAMS (Groundwater Loading and Evaluation of Agricultural Management Systems, Leonard et al., 1987) simulation model, (2) databases and default values for parameterizing the simulation model, (3) a decision model with embedded scoring functions and an algorithm for ranking alternatives, (4) a system driver, and (5) a user interface and report generator. Further details of the P-MODSS are given by Yakowitz et al. (1992a,b).

The decision model is based on multiobjective decision theory that combines the dimensionless scoring functions of Wymore (1988) with the decision tools presented in Yakowitz et al. (1992b;1993). The scoring functions convert predicted

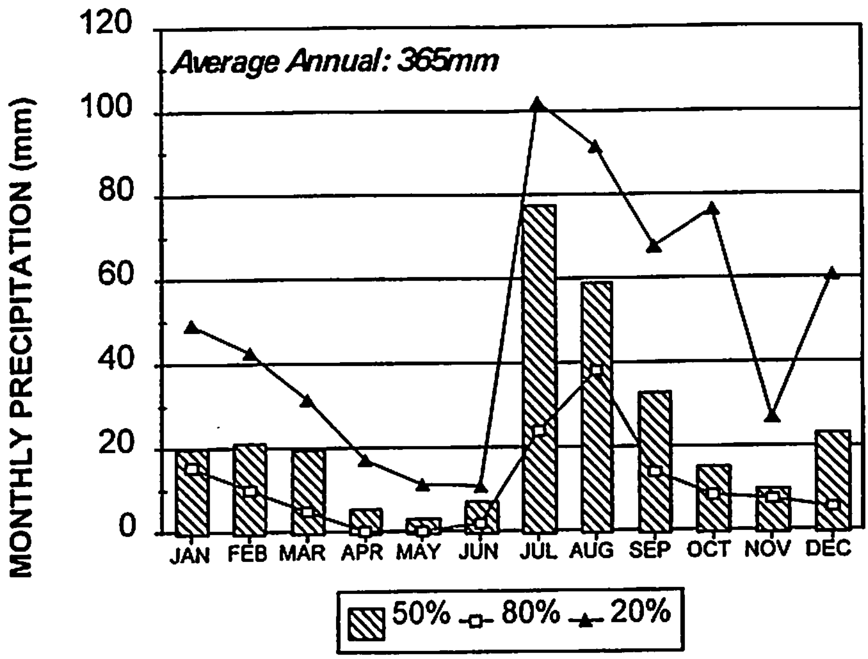

Figure 31.1 Distribution of monthly precipitation for 50, 80, and 20% probability of exceedence, watershed WS1 (1976 to 1991).

or observed data to a unitless scale of 0 to 1, where 0 is the worst and 1 is the best possible score. The scoring functions are a means of scaling each decision criteria by which the current and alternative management systems are evaluated. The four generic scoring functions are more is better, more is worse, a desirable range, and an undesirable range (Figure 31.2). Net returns and productivity are examples of decision criteria that would be associated with the more is better scoring function shape, while erosion would be associated with the more is worse score shape. The functions are constructed such that the average annual value of the management system conventionally used is assigned the score of 0.5 for all decision variables. The slope of the function at the score of 0.5 is determined by the annual minimum and annual maximum values of the decision criteria. The scores of the decision criteria for alternative management practices are computed in relation to the conventional system.

The importance order of the decision variables can be specified by the user or computed by the normalized slope of the function for the conventional management system. This latter method is the default importance order and assigns more value to those decision criteria for which small differences in the values of the alternative criteria make a large difference in the score. After the importance order has been determined, a best and worst composite score is computed by the method developed by Yakowitz et al. (1992b) using two linear programs for each alternative. This method is a feature of the P-MODSS which eliminates some of the subjectivity associated with assigning weights to the decision criteria. Finally, the alternatives are ranked in descending order according to the average of the best and worst composite scores. The preferred or "best" alternative is the one with the highest average score.

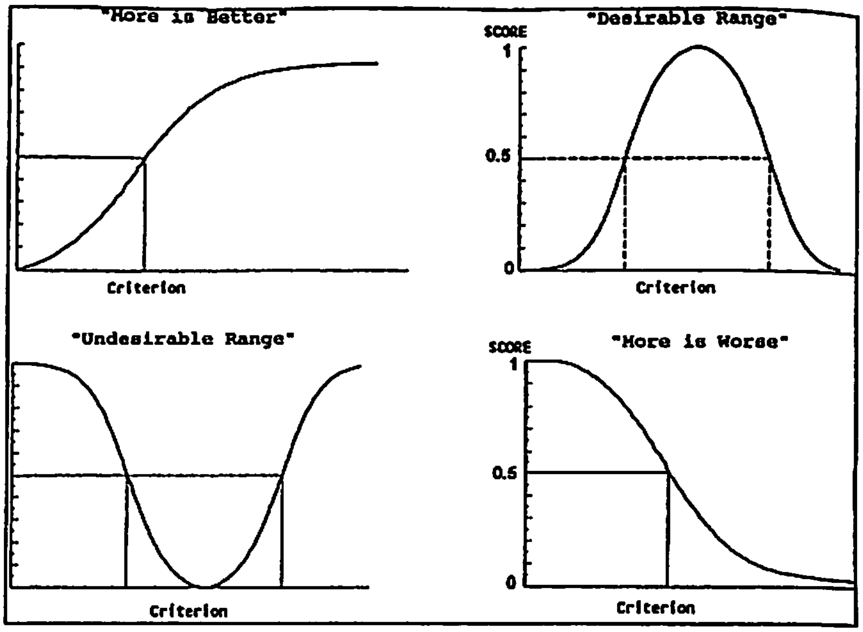

Figure 31.2 Generic scoring function types and shapes (based on Wymore, 1988).

Selection of Decision Variables

The National Research Council (1994) Committee on Rangeland Classification has developed a number of indicators to judge rangeland health. Among these, soil stability, soil erosion, and watershed function are considered to be important indicators of rangeland health. Using the 16 years of recordings from the Santa Rita watersheds, four measurements were selected as decision variables to evaluate the grazing and land management systems. These decision variables were annual runoff (mm), maximum annual peak rate of runoff (mm/hr), annual sediment yield (t/ha), and annual aboveground net primary production (g/m^2). Annual runoff, peak rate of runoff, and total annual sediment yield were calculated from measured data for the period 1976 to 1991 for each watershed and used to quantify the decision variables. ANPP is the total aboveground dry weight biomass produced per unit area in a growing season. Relationships between annual actual evapotranspiration and ANPP are given by Rosenzweig (1968), Webb et al. (1978), Lane and Stone (1983), and others. Lane and Stone (1983) showed that, in the absence of detailed information, annual actual evapotranspiration can account for 80% of the variation in ANPP. Using the discrete form of the water balance equation, annual actual evapotranspiration was derived as the difference between annual precipitation and annual runoff, assuming negligible percolation losses. The estimate of actual evapotranspiration for WS1 and WS3 was reduced by the coverage of mesquite and other woody shrubs (17 and 22%, respectively) to reflect the ANPP for grass forage. In this respect, ANPP was intended to represent a surrogate for productivity, although not a direct indicator of economic returns to the rancher.

Hence, the impact of each grazing and vegetation management system on factors that affect the volume and discharge of surface water, soil loss, and productivity were considered through the selection of the decision variables. It is emphasized that the analysis represented only a preliminary assessment of rangelands using measured data. As multiobjective databases are extended and more complex rangeland and ecosystem simulation models are considered, more decision criteria will need to be included in the evaluation. Further, the decision variables are not reflective of off-site effects nor do they address the objectives of broader issues of natural resource conservation.

Scoring Functions

The scoring function type more is worse was chosen for the decision variables of depth of runoff, peak rate of runoff, and sediment yield. In this sense, the preferred management system should minimize these physical resource decision variables. ANPP, as a surrogate for productivity, used the scoring function type "more is better."

Management Systems Evaluated

The four grazing and vegetation management systems evaluated were yearlong grazing (YL) and rotation grazing (ROT), each with (+m) and without (-m) mesquite vegetation.

Results and Discussion

The evaluation of rangeland management systems is discussed first using only the measured and estimated data from the experimental watersheds. This was done to demonstrate that it is possible to identify preferred management systems without the use of a computerized DSS. Following this initial analysis, an evaluation was performed by incorporating the information from the measured data into the P-MODSS. This evaluation takes advantage of two features of the P-MODSS, namely the importance order of the decision variables and the type of scoring function, to assess practical, multiobjective decision making scenarios that are normally not possible from a simpler analysis of measured data.

Evaluation without a Decision Model

Average annual values for the four decision variables (runoff depth, peak rate of runoff, sediment yield, and ANPP) for each grazing and vegetation treatments are given in Table 31.2. The results showed that the yearlong grazing treatments produced less annual runoff and sediment yield and lower peak discharge compared to the rotation grazing systems. This finding may be associated with the higher density of perennial grasses in the yearlong grazed watersheds. Martin and Morton (1993) reported that during 1985 and 1986, low summer rainfall, coupled

Table 31.2 Average Annual Values for Physical Resource Decision Variables. Coefficient of Variation (%) shown in brackets.

	Grazing and vegetation practice			
Decision variable	*Yearlong + mesquite WS 1 Conventional*	*Yearlong + no mesquite WS 2 Alternative 1*	*Rotation + mesquite WS 3 Alternative 2*	*Rotation + no mesquite WS 4 Alternative 3*
Annual runoff	18.7	13.2	40.8	37.3
Peak runoff rate	24.3	21.8	32.6	35.7
Sediment yield	1.4	0.8	7.3	7.1
ANPP	74.1	103.7	66.5	85.6

with March to October grazing in 1986, resulted in the grass density in the rotation grazing watersheds being less than half that measured in the yearlong grazing watersheds. Rainfall during 1985 was almost 20% below the annual mean. Martin (1973) observed that recovery of grass density after dry conditions was slow if March to October grazing was imposed during drought or in the summer following drought. The lower density and coverage of grass, in association with the soil texture, may be responsible for the greater runoff from the rotation grazed watersheds (WS3 and WS4) compared to the yearlong grazed watersheds (WS1 and WS2). To support these differences, an examination of the frequency of runoff events showed that the yearlong grazed watersheds averaged almost half the number of runoff events (11 per year) compared to the rotation grazed watersheds (19 events per year).

When the results in Table 31.2 were grouped according to the vegetation management, the mesquite-free watersheds (WS2 and WS4) produced less runoff and sediment yield and more ANPP than the mesquite-invaded watersheds (WS1 and WS3). The estimated ANPP was 35% greater on the mesquite-free watersheds than on the mesquite watersheds. The effect of vegetation manipulation on the mean annual peak runoff rate and the mean annual frequency of runoff events was indistinguishable.

This examination of the effect of grazing and vegetation treatments on the selected physical resources yielded several outcomes. First, it suggested that yearlong grazing was preferred to rotation grazing if the desired intention was to maximize ANPP and minimize runoff and sediment yield. Second, controlling mesquite satisfied both goals of natural resource conservation and production. Hence, the results indicated that the practice of controlling mesquite and yearlong grazing represented the preferred management system for southern Arizona rangelands. However, this outcome was somewhat limited in terms of considering other important factors associated with grazing and ranch management, such as economics, labor and management for stock handling, fencing, herd composition, and the biophysical limitations of the land. In addition, the outcome was independent of the impact on broader, multiobjective issues such as wildlife habitat, human perception of the use of rangelands, and the general concepts of integrated resource management. Finally, the outcome was based on the implicit assumption that the four resource decision variables were of equal importance.

Evaluation Using a Decision Model

The application of a DSS is designed to enhance and assist the land manager make decisions on effective land management. This is normally done by comparing the current conventional practice to a number of feasible alternative management practices. For this study, yearlong grazing with mesquite (YL+m) was selected as the conventional practice and compared to the other management systems on the basis of the four physical resource decision criteria. Three analyses were performed to demonstrate some of the advantages of using the P-MODSS to evaluate the sustainability of rangelands in the Southwest. These analyses were

1. An evaluation with equal importance attached to the four decision variables.
2. An evaluation using the default importance order attached to the decision variables.
3. An evaluation when the scoring function for depth of annual runoff is changed from more is worse to be more is better. This scenario represented the basis for earlier research into vegetation manipulation for water yield enhancement in Arizona (Hibbert, 1965; Ffolliott and Thorud, 1974).

Decision Variables with Equal Importance

The results of the analysis using the P-MODSS to evaluate the four management systems when equal importance was placed on the decision criteria are given in Figure 31.3. Clearly, the YL-m was the most preferred system. The two rotation systems (ROT+m and ROT-m) were less preferred to the two yearlong systems. This outcome is consistent with the earlier examination of the measured data.

Decision Variables with an Importance Order

The P-MODSS allows the user to select an importance order for the decision variables. This is a realistic feature designed to accommodate a particular preference associated with the decision criteria. For example, the user may wish to place higher importance on surface runoff than on the other decision variables. The default ordering of the criteria ranks highest that criterion which has the potential for the greatest change in score when a small change in the criteria near the conventional practice is observed (Yakowitz et al., 1992b). The score matrix for the decision variables with the default importance order is given in Table 31.3. Ranking the decision criteria by the normalized value of the slopes of the scoring functions resulted in a default importance order of (ranked from most to least importance): ANPP > sediment yield > runoff depth > peak rate of runoff.

Figure 31.4 shows the best (top line of bar) and worst (bottom line of bar) composite scores for the default importance order. When greatest importance was placed on ANPP, YL-m dominated the conventional (YL+m) and the alternative grazing and vegetation management systems. On the basis of the average composite score, YL+m was preferred to ROT+m and ROT-m. However, the length of the bars in Figure 31.4 suggested the outcome was highly sensitive to a particular weight vector consistent with the importance order. For some possible weighting schemes, ROT-m was equal to or better than YL+m, but for the majority of the weighting

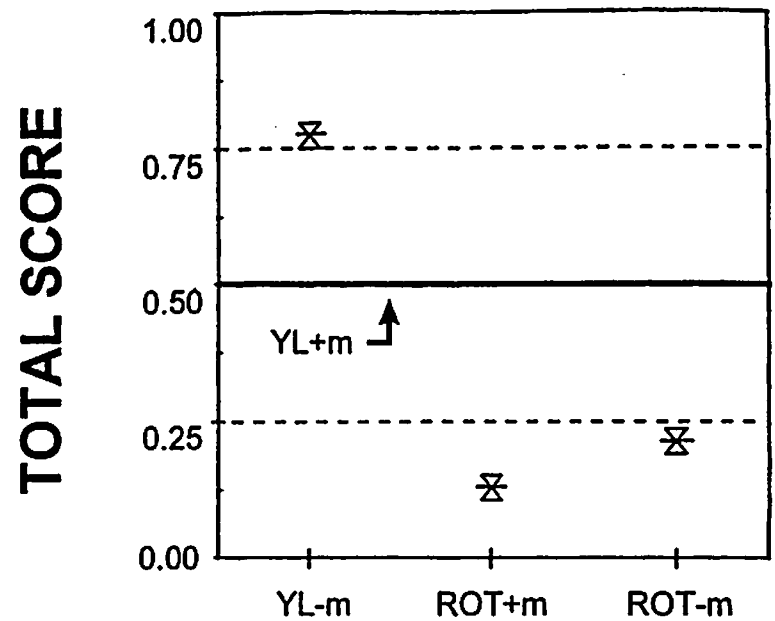

Figure 31.3 Composite scores for yearlong (YL) and rotation (ROT) grazing with (+m) and without (-m) mesquite vegetation with an equal importance order for the decision variables.

Table 31.3 Score Matrix for Decision Variables with Default Importance Order

	Grazing and Vegetation System			
Decision variable	*Yearlong + mesquite WS 1 Conventional*	*Yearlong + no mesquite WS 2 Alternative 1*	*Rotation + mesquite WS 3 Alternative 2*	*Rotation + no mesquite WS 4 Alternative 3*
Annual runoff	0.5	0.787	0.004	0.011
Peak runoff rate	0.5	0.611	0.178	0.110
Sediment yield	0.5	0.524	0.291	0.299
ANPP	0.5	0.931	0.341	0.729

schemes, this alternative was less preferred to the conventional system of yearlong grazing with mesquite. The ROT+m alternative was the least preferred system.

Modifying the Scoring Functions

In the above analyses, the depth of runoff was associated with a scoring function type of "more is worse." However, in an environment where water is a limiting factor, a rancher may be interested in grazing systems that generate runoff for water harvesting projects and water supply for stock dams.

To evaluate this option, the scoring function type for runoff was changed to "more is better" and the P-MODSS used to reevaluate the management systems.

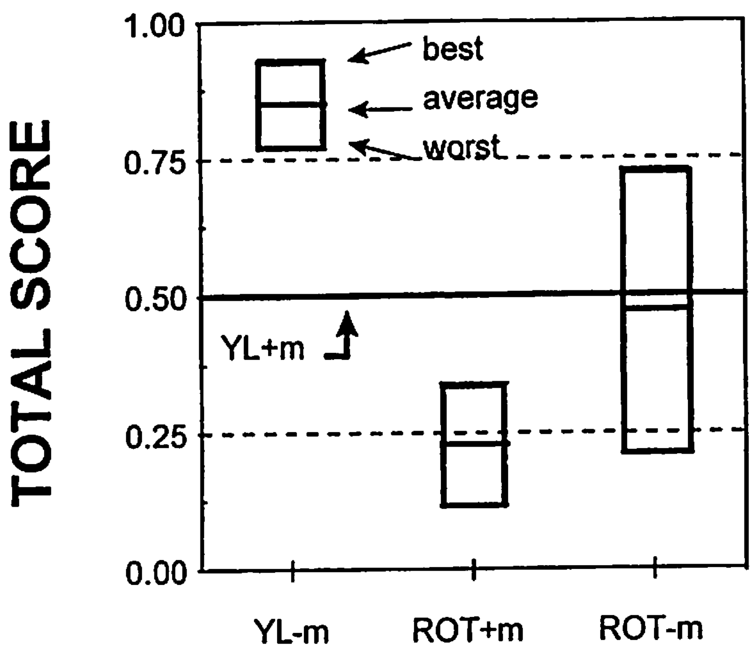

Figure 31.4 Composite scores for yearlong (YL) and rotation (ROT) grazing with (+m) and without (-m) mesquite with a decision variable importance order of ANPP > sediment > runoff > peak runoff rate.

This changed the score matrix for runoff for YL-m to 0.213, for ROT+m to 0.996, and for ROT-m to 0.990. All other values of the score matrix were unaltered from the values shown in Table 31.3. For the initial evaluation, the default importance order (ANPP > sediment yield > runoff > peak runoff rate) was used. The scoring functions for ANPP, sediment yield, and peak runoff were unchanged.

The results of best and worst scores following the adjustment to the runoff scoring function are shown in Figure 31.5. When the average composite score is used to rank the alternatives, YL-m was again found to be the preferred system. The ROT-m system was also preferred to the conventional system of YL+m. Changing the scoring function for runoff from "more is worse" (Figure 31.4) to "more is better" (Figure 31.5) increased the sensitivity of the outcome for YL-m but reduced the sensitivity of the outcome for ROT-m.

Next, an importance order was imposed so that runoff and sediment yield were of equal importance, but with a higher importance order than ANPP and peak runoff rate. With this imposed importance order, the rotation grazing systems (ROT+m and ROT-m) were marginally preferred to the yearlong grazing systems (Figure 31.6). No one alternative completely dominanted the other two. Given the importance order of the decision variables, the ROT-m was the most preferred system, and the YL-m the least preferred system.

As a final examination of grazing and vegetation systems, the importance order of the decision variables was adjusted to give sediment yield the greatest importance (i.e., sediment > runoff > ANPP > peak runoff rate). In Figure 31.7, the results showed that when sediment was the primary concern ahead of runoff, ANPP, and peak discharge, there was little to distinguish between the alternatives

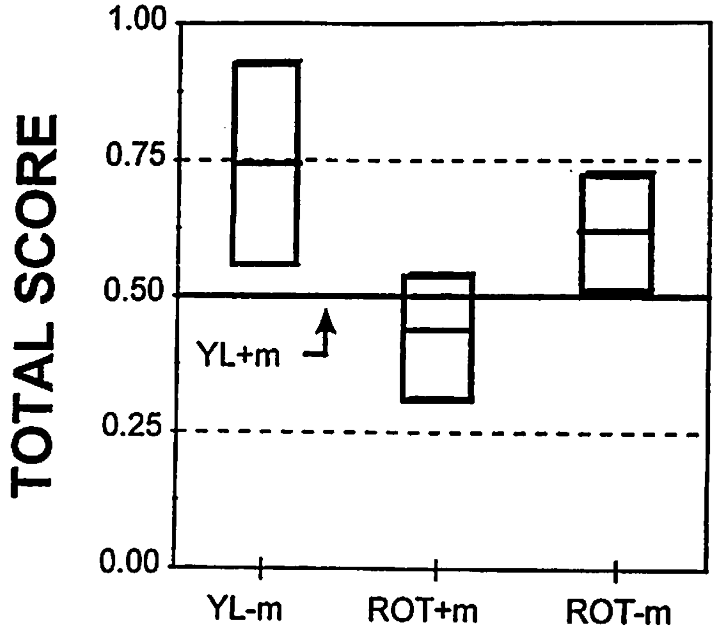

Figure 31.5 Composite scores for yearlong (YL) and rotation (ROT) grazing with (+m) and without (-m) mesquite with a decision variable importance order of ANPP > sediment > runoff > peak runoff rate. Scoring function for runoff is "more is better."

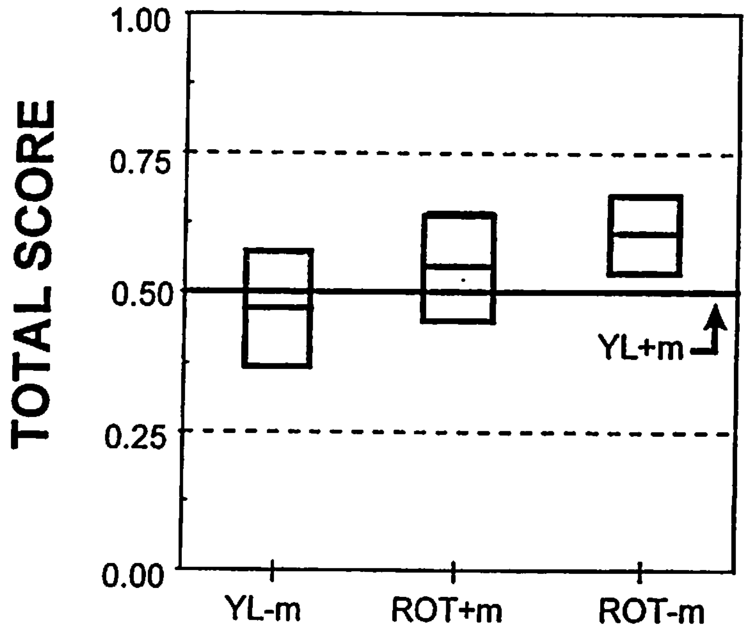

Figure 31.6 Composite scores for yearlong (YL) and rotation (ROT) grazing with (+m) and without (-m) mesquite with a decision variable importance order of runoff = sediment > ANPP > peak runoff rate. Scoring function for runoff is "more is better."

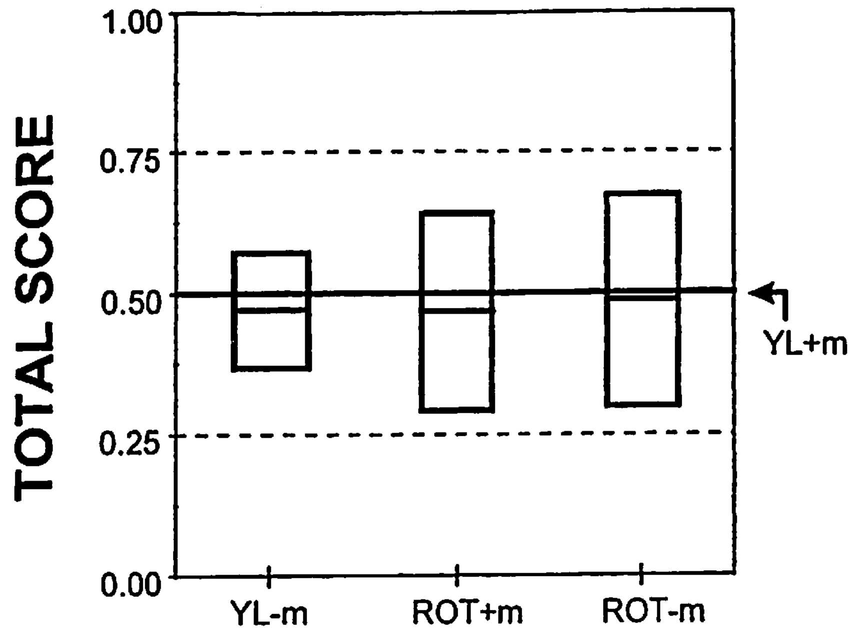

Figure 31.7 Composite scores for yearlong (YL) and rotation (ROT) grazing with (+m) and without (-m) mesquite with a decision variable importance order of sediment > runoff > ANPP > peak runoff rate. Scoring function for runoff is "more is better."

and the conventional management systems. The average score for all alternatives ranged from 0.47 to 0.49, and all were less than the 0.5 score associated with the conventional treatment. Figure 31.7 showed that the alternatives differed in the length of the bar, suggesting that the composite score for YL-m was the least sensitive to the weights consistent with the importance order.

Summary and Conclusions

A preliminary analysis was undertaken of the extensive rangeland areas represented by the grazing and vegetation management systems monitored on the Santa Rita Experimental Range in southwestern Arizona using a prototype DSS. Of the four rangelands management systems considered, the P-MODSS identified yearlong grazing with mesquite removed as a preferred system when it was desirable to maximize ANPP and minimize runoff depth, sediment yield, and peak discharge. This treatment produced the highest average composite score regardless of the importance order given to ANPP, sediment yield, and runoff. However, when the scoring function for runoff was changed from "more is worse" to "more is better" to reflect the limitations of water in a dry environment, and sediment yield and runoff were given equal importance, then the rotation grazing systems were preferred to the yearlong grazing system. Alternatively, when sediment yield was given the highest importance, all four systems considered in this evaluation were almost identical, but yearlong grazing with mesquite removed displayed the least sensitivity of the outcome to a given weighting vector. Based on the conditions and data set from the experimental watersheds, these evaluations suggested that yearlong grazing with no mesquite was a management system which reflected a stable balance of conservation and productivity objectives.

There are two important considerations for the use of a MODSS for evaluating rangelands. First, a quantitative framework is available to assess current and alternative practices of grazing and vegetation control. This framework incorporates technical information about the management system by quantifying the decision variables and the desirable utility of the decision variable through the selection of the scoring function type. Second, the user can adjust the importance order of the decision variable without the need of assigning weightings. This is a feature of the P-MODSS and one which encourages the full application of a MODSS to explore scenarios for natural resource conservation. Hence, the P-MODSS can make a valuable contribution towards the nation's assessment of rangeland health and ecological condition.

Future work using the P-MODSS on rangelands needs to address the limitations encountered with this preliminary work. First, the decision variables need to be quantified using a continuous, dynamic simulation model. This would allow long-term values to be used and consideration may be given to increase the number of decision variables in the evaluation (e.g., seasonal timing of soil water storage, alternative land uses, interactions between livestock and wildlife, vegetation composition, a more detailed economic analysis). Second, data are needed to expand the scope of decision variables to integrate off-site, sustainability, and socioeconomic aspects of rangelands.

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