AN EVALUATION AND COMPARISON OF CURRENT TECHNOLOGIES FOR STOCKING RATE MANAGEMENT

A Thesis

by

TRAVIS SCOTT HABY

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 1998

Major Subject: Rangeland Ecology and Management

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ABSTRACT

An Evaluation and Comparison of Current Technologies for Stocking Rate Management.

(August 1998)

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Selection and management of stocking rate is considered to be critically important to the management of grazing lands. Numerous methods have been devised to address stocking rate decisions. A review of the literature failed to find a study concerning the effects of long-term use of these methods. Studies concerning comparisons between methods with respect to estimates of the same or similar parameters were scarce. Four methods were applied to the same study site and the results were compared. Methods were evaluated for repeatability; scope of application; ease of use; and knowledge, skills, and abilities needed for implementation. Average carrying capacities generated from TGM set at a target use rating (TUR) of 2, the range condition method, and POPMIX did not differ significantly. Average carrying capacities generated from TGM set at a TUR of 3 were significantly different than range condition and POPMIX. Annual carrying capacities generated by the forage survey method (TOTAL) and a modification to the forage survey method (FORAGE) were significantly different. Annual carrying capacities from TGM and FORAGE did not differ significantly. Annual carrying capacities from TGM and TOTAL differed significantly at the 0.10 level but not at the

0.05 level. Some range site stocking rates from POPMIX and range condition showed drastic variations between years and methods. Average carrying capacities from TGM for two years did not differ significantly but showed a year effect. Range condition, forage survey, and POPMIX have possible limitations to universal application due to their use of range sites. Ease of use varies with the presence of a serviceable manual. Knowledge, skills, and abilities needed vary by method but all can be acquired.

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INTRODUCTION

Stocking rate is one of the most important factors affecting a grazed biotic system. Stocking rate acutely influences the health and composition of the vegetation, the profitability of ranching enterprises, habitat for wildlife, soil integrity, and hydrology (Holechek et. al 1989, White and McGinty 1992, Hanselka and Landers 1993). Selection of the correct stocking rate has been the most basic problem confronting grazing land managers since the inception of the range management profession (Holechek et. al 1989). Until recently, specific approaches to this problem have been largely non-existent. A method designed as a guide to initial stocking rate had been established, but beyond that, experience and intuition have been the guiding factors.

Procedures are now available that attempt to quantify stocking rate decisions. These procedures differ in format, theoretical basis, skills and knowledge level required, factors to be estimated, scope of use, and information provided. Little is known about how the information provided by these methods compares when they are applied to the same management unit. Evaluation and comparison of the procedures is needed to discern their applicability and comparability. Since actual carrying capacity is not a measurable entity, these methods cannot be tested for accuracy concerning actual carrying capacity. Therefore there is no way to definitively determine which method gives the most accurate information.

This thesis follows the format of the Journal of Range Management.

In light of these factors, this study was designed to accomplish the following:

1. Apply methods representing different basic theoretical approaches to deriving carrying capacity and managing stocking rate to the same study site.
2. Compare results derived from the different methods with respect to estimates concerning the same or similar parameters.
3. Evaluate the methods for repeatability.
4. Evaluate the scope of application; ease of use; and knowledge, skills, and abilities needed for implementation of each method by grazing land managers.

LITERATURE REVIEW

Correct determination of proper stocking rate is thought to be one of the most important decisions confronting a grazing-land manager. White and McGinty (1992) state that stocking rate determines animal performance, financial returns, and the long-term condition of the range. Holechek and Pieper (1992) assert that of all grazing management decisions, selection of the correct stocking rate is the most important from the standpoint of vegetation, livestock, wildlife, and economic return. After analyzing over 50 grazing experiments in South Africa, O'Reagain and Turner (1992) concluded that stocking rate is a major determinant of both range condition and animal production, and is possibly the most important management variable under the direct control of the grazier. Walker (1995), in his invited viewpoint article on grazing management, says, " Stocking rate is the most important variable in grazing management. If stocking rate is not near the proper level then regardless of other grazing management practices employed objectives will not be met".

It would seem, considering the importance placed upon stocking rate, that a methodology to enable determination of proper levels of stocking would be paramount to rangeland scientists and managers. Indeed, several methods designed to facilitate stocking rate management on rangelands have been published. These methods vary in their scope of application, input data required, complexity, use of models, objectives, and theoretical basis. These methods attempt to quantify the available capacity of a rangeland management unit to support herbivores.

The methods described include those for which the input data can theoretically be gathered by grazing managers. Economic models and in-depth simulation models were not considered. This review focused on methods that represent a broad array of theoretical approaches and were available through the literature.

Methods

Lacey et al.

Lacey et al. (1994) describe a procedure for analyzing the forage-livestock balance on ranches. This Montana State University Extension Service publication did not mention the scope of application of the guide but the authors acknowledge that the methodologies and approaches described were developed by J. Workman, Range Economist at Utah State University and by S.S. Waller, L.E. Moser, and B. Anderson at the University of Nebraska. Of interest is the approach to setting stocking rates for rangeland. A similar method was published by the Alberta Department of Agriculture (Johnston et al. 1966). However, Lacey et al. simplifies range site classification by grouping native range sites into three categories: normal, run-in, and run-off. Normal sites are not affected by soil or moisture limiting factors and thereby allow vegetation to make normal response to climate. Run-in sites produce more vegetation than normal sites by virtue of superior soil moisture. Coulees, bottomlands, overflow and subirrigated sites are included in the run-in category. Run-off sites produce less vegetation than normal sites because they have topographic features or characteristics that limit soil moisture availability. Shallow, very shallow, thin hilly, dense clay, and badland sites are included in the run-off group. Range site categories should be sampled for species composition by weight and that information used to label them as being in excellent, good, fair, or poor condition, based on the percentage of similarity to original vegetation. Range sites with over 75 % similarity receive a rating of excellent, 51-75% is good condition, 26-50% is fair, 0-25% is poor condition. Initial suggested stocking rates for the three categories of range sites under two levels of precipitation (10-14 in. and 15-19 in.) are listed in a table. These stocking rates are for rangeland in good condition and assume season-long, continuos grazing. The authors state that for range in fair condition the initial suggested stocking rates would be about one-third less than the values listed in the table. They make the statement that under these levels of stocking about 50 percent of the vegetation is left to promote plant vigor, 25 percent is harvested by livestock, and 25 percent of the total yield is lost to wastage, trampling, and other herbivores. The authors suggest that if initial suggested stocking rates appear unrealistic, they can be checked by measuring the amount of forage available. Annual forage yield is checked by clipping plots of ungrazed forage when forage growth reaches its peak. Forage is then dried and converted to pounds per acre and a harvest efficiency of 25 percent is applied.

McInnis et al.

McInnis et al. (1990) describe a simple deterministic model to predict animal unit months (AUM) of cattle for specific range types in eastern Oregon. Pastures are mapped by "resource unit" (RU); a combination of ecosystem, productivity level, and condition class. Four slope classes and 5 proximity-to-water classes are used to categorize the area within each RU. This results in a unique set of slope/proximity to water cells within each within each RU. This results in a unique set of slope/proximity to water cells within each RU. Each cell is assigned a use factor. The use factor is a function of slope and distance to water and is intended to estimate the percentage of acres within each cell likely to be used by cattle. The usable acres of each cell are calculated by the model as the product of the use factor and the number of acres within the cell. The pounds per cell of available forage is calculated as FORAGE by the equation:

$$FORAGE = FORAVA * USABLE\_ACRES$$

A subroutine calculates the variable *FORAVA* as a function of several parameters. (1) A desired level of forage utilization is assigned to each forage class. (2) Biomass within RU's is measured by forage class at time of peak standing crop. Forage classes are grass, forb, and shrub. Percentages are assigned to each forage class to adjust for dietary preferences. Biomass can be further adjusted by the use of a calibration factor. The calibration factor represents the ratio of actual AUMs to estimated AUMs and is determined through repeated observations of actual AUMs for given ecosystems. (3) A factor is used to convert from g/m^2 to lb/ac. (4) A yield index is used to adjust forage biomass measurements to a common precipitation year. (5) A percent production factor accounts for seasonal variability of forage biomass.

The model first calculates AUMs within each slope, proximity-to-water cell as a quotient of available forage within a cell and the dry matter requirement of a 1000 lb animal unit for 30 days (750 lbs). The model provides output expressed in AUMs per acre by ecosystem.

Scanlan et al.

Scanlan et al. (1994) describe a systems approach to estimate safe carrying capacity for individual properties in north-eastern Australian eucalypt woodlands. Stocking rates are calculated with the following equation:

$$SR_{safe} = 100 * (growth_{actual} * utilization_{safe}) / consumption_{summer}$$

Where: SR_{safe} is a stocking rate (head/100 ha) that produces safe levels of pasture usage; $utilization_{safe}$ (0.3) is the percent utilization, expressed as a ratio, that will give safe utilization; $consumption_{summer}$ (1850 kg/hd) is the intake requirement of an adult animal over the summer period assuming a liveweight gain of about 140 kg/hd; and $growth_{actual}$ is the actual forage production. Actual forage production is calculated by the following equation:

$$growth_{actual} = growth_{potential} * condition_{index} * tree_{index}$$

$Growth_{potential}$ is the potential forage production, $condition_{index}$ is actual pasture production relative to potential production described as a function of initial pasture basal area and rainfall, and $tree_{index}$ is the ratio of actual growth within woodlands to potential growth without tree competition. Potential forage production is calculated as follows:

$$growth_{potential} = RUE_{unit} * VPD_{index} * rain_{summer}$$

The approach to estimating potential pasture productivity for a particular soil type is to assume a linear relationship between potential production and rainfall. The slope of the line relating production to rainfall is the rainfall use efficiency (RUE_{unit} reported as kg/ha/mm rain). Each pasture association has a characteristic RUE; however, RUE_{unit} can vary between years as a result of differences in average seasonal atmospheric vapor vary between years as a result of differences in average seasonal atmospheric vapor pressure deficit (VPD). On a seasonal basis, average VPD is a function of seasonal rainfall. To allow one value of RUE_{unit} to be used for all years for the one land unit, the RUE at a VPD of 20 hPa is used. This value is an average for much of sub-coastal Queensland. To calculate the RUE at other VPD, the following equation is used to calculate an index by which RUE must be multiplied:

$$VPD_{index} = 20 / VPD$$

$Rain_{summer}$ is the amount of summer rainfall. Summer rainfall is used because high utilization can damage perennial grass pastures. In any one year, winter growth can be important but is relatively unimportant in terms of long-term mean yearly production. Thus, the potential pasture production, including the effect of VPD on a seasonal basis, can be calculated.

$Condition_{index}$ (actual pasture production relative to potential production) is described as a function of initial pasture basal area and rainfall. $Condition_{index}$ used to modify potential growth can be read from a figure that relates it to pasture basal area at the start of the growing season and growth conditions.

The $tree_{index}$ (ratio of actual growth within woodlands to potential growth without tree competition) is shown by the following equation:

$$tree_{index} = growth_{tree} / growth_{potential}$$

Where $growth_{potential}$ is as described previously and $growth_{tree}$ is as follows:

$$growth_{tree} = 0.45 * growth_{potential} + 0.55 * 0.55 * growth_{potential} * e^{(-k*tree\_basal\_area)}$$

Growth is in kg/ha and tree basal area is in m^2/ha. The equation relating k to growth for northern eucalypt woodlands is as follows:

$$k = 0.48 * e^{(-0.0005 * growth_{potential})}$$

Merrill

Merrill (1993) developed a method, which he states is fast and easy to learn and use in a yearlong grazing area. Author has used it for 20 years and says it has proven accurate. It is based on estimating the total forage production per acre in the fall at or near the end of the growing season to determine the carrying capacity through the dormant season. Pounds of forage per acre is estimated, either per range site and totaled for the pasture or as an average of the pasture. Pounds per acre are multiplied by the number of acres to determine the total pounds of forage. The eye of the manager can be set for visual estimates by training. Forage is clipped from a 21 inch radius circle and weighed in grams and multiplied by 10 to determine pounds per acre. It is adjusted for moisture to arrive at air dry forage (lb/ac). The author states this procedure comes very naturally to those accustomed to estimating livestock weights.

One fourth of the total forage in the pasture is available for animal intake. This allows for the amount already grazed during the growing season, the amount lost to weathering and trampling, and the amount that should be left for soil protection to achieve proper use at the end of the grazing season before the following year's growth is initiated. The amount of usable forage required per animal is determined by multiplying 3% of the body weight of stock by the days to be grazed. Days of grazing is dormant season plus 30 to 45 days to allow for a late spring or a shorter period if livestock are to be rotated. If the pasture is being grazed yearlong, the winter stocking rate will approximately equal the yearlong stocking rate.

Holechek

Holechek (1988) provides some guidelines for establishing an initial stocking rate for a particular range. He states that the stocking rate will probably have to be adjusted as experience is gained with actual animal use of the pasture. Information should be obtained on range condition, average annual precipitation, total precipitation during the previous 12 months, total area in the pasture, physical characteristics of the pasture (topography and water distribution), average standing crop of grazeable forage, average weight of the animals to be grazed, and length of time for grazing. Total usable forage is calculated as follows:

$$Forage\_production(lb / ac) * \% allowable\_use * pasture\_acreage$$

No information is given as to how forage production estimates should be obtained. Percent allowable use is taken from a table of allowable uses for different range types. Factors to be considered are average annual precipitation, range type, and range condition. No information is provided as to how to ascertain range condition.

Forage demand (lb) per animal for the grazing season is calculated in the following formula:

$$Weight\_of\_animals(lb) * Daily\_dry\_matter\_intake\_(\%)\_body\_weight * Number\_of\_days\_pasture\_will\_be\_grazed$$

Weight of animals should be the average weight of the animals. *Daily dry matter intake*

(%) body weight should be calculated as the ratio of daily dry matter intake to average body weight. The author says this is 0.02.

The stocking rate is calculated as the number of head that can be run in the pasture:

$$Total\_usable\_forage(lb) / Forage\_demand(lb)\_per\_animal\_for\_the\_grazing\_season$$

Animal numbers should then be adjusted based on factors derived from comparing the total precipitation in the last 12 months to the average annual precipitation. If previous 12 months precipitation is more than 125% and less than 150% of annual average precipitation, a 30% downward adjustment in animal numbers should be made. If previous 12 months precipitation is between 70% and 50% of the average annual precipitation, animal numbers should be adjusted 30% upward. Finally, animal numbers should be adjusted for topography and distance from water according to adjustments provided in tables.

Lance

Lance (1987) describes a multiple regression model adapted for predicting trends in heather cover at different stocking densities of sheep, cattle, and deer – alone or in combination – using input data commonly available to the land manager. Site factors are included, allowing the model to be generalized to moorland at different elevations, soils, and climatic zones. D. Welch (1984) studied relationships between animal numbers and moorland vegetation over a typical range of variation in both. Welch used regression models with a capacity for prediction and trends in heather cover as a yardstick of response. Trends in heather are of fundamental interest to moorland conservation, serving as a broad index of floral and faunal status. Welch's technique compared some 7 types of independent factors against various measures of heather trend in simple and multiple regressions, reducing the factors and regressions step-wise to find a combination (regression model) which left the smallest residual variation (1-R2) in heather trend. The author states that Welch's models are of little practical use and were modified by using several less than robust assumptions. The model's prediction of heather trend is probabilistic rather than absolute, merely giving "best estimates" within a range of other (though less likely) values. Inputs for the model are heather production per unit area (can be estimated if altitude is known), pH, altitude, stocking levels of cattle, and stocking levels of other herbivores. Of real significance is that stocking levels which equate to zero change in heather cover can be calculated through an iterative process. A program in BBC BASIC is available upon request.

Hanley and Rogers

Hanley and Rogers (1989) developed a procedure for estimating carrying capacity (the number of animals of a given species that can be supported per unit area of habitat) on the basis of two simultaneous nutritional constraints; dietary concentrations of digestible energy and digestible protein. The procedure requires specifying the quantity (biomass) and quality (chemical composition and/or digestibility) of available food and the nutritional requirements of the animal species. The model provides an iterative solution by calculating the maximum biomass obtainable from a mixture of forages while satisfying three constraints: a specified minimum concentration of digestible dry matter (or digestible energy), a specified minimum concentration of digestible protein, and a specified maximum percentage of any single species in the diet. Only biomass greater than a certain kg/ha is available for consumption. The user may set the constraints and biomass factor.

The required habitat inputs are available biomass (kilograms per hectare) by plant species (or other food categories) and concentrations (percentage dry weight) of digestible dry matter and digestible protein of each. The required data inputs for the animal are the dry matter intake rate (kilograms per day per animal) and the minimum dietary concentrations of digestible dry matter and digestible protein needed to meet nutritional requirements at the given rate of intake.

The maximum quantity of biomass obtainable from the habitat while satisfying all three constraints is then calculated by proceeding through the following five steps: (1) Ignore the protein constraint and solve for the dry matter digestibility (DMD) constraint by successively adding the biomass of each species, beginning with the highest and working toward the lowest DMD until the average DMD concentration of the biomass reaches the minimum constraint. Check to see if the single species maximum concentration constraint has been exceeded; if so, reduce accordingly the amount of biomass of that species and repeat the procedure until both the DMD and percent maximum constraints are satisfied. Then calculate the protein concentration for that particular combination of biomass. (2) Step 1 should be repeated for protein concentration while ignoring the DMD constraint. The DMD for that particular combination of biomass should then be calculated. (3) If either step 1 or step 2 results in zero biomass, the authors state that carrying capacity is zero and there is no solution. (4) A possible solution occurs when either step 1 or step 2 satisfies both the DMD and the protein constraint. However, if only one of the steps satisfies both constraints, it is the solution. If both step 1 and step 2 satisfy both constraints, the greater biomass of the two is the solution. (5) If neither step 1 or step 2 satisfies both constraints but both yield biomass greater than zero, then the solution is found by beginning with the inclusion of all species that had 100 percent of their biomass included in both step 1 and step 2. Additional species are added in the order of the greatest amount of biomass that can be added while still satisfying both DMD and protein constraints until no additional biomass can be included without violating either constraint. The single species maximum concentration constraint is checked to see if it has been violated. If it has been violated, the biomass of that species is reduced accordingly, and the procedure is repeated until all three constraints are satisfied.

When the maximum amount of biomass (kilograms per hectare) obtainable from the habitat has been determined, the kilograms per hectare constraint should be subtracted. The result is divided by the specified dry matter intake rate (kilograms per day per animal), which yields the estimate of carrying capacity (animal days per hectare).

Bosch and Booysen

Bosch and Booysen (1992) developed a comprehensive system containing a data base, expert system, and simulation models designed to serve as a basis for rangeland condition and grazing capacity assessment. They state that the system can be applied universally, regardless of the pool of quantitative knowledge that exists. The database holds specific information and rules about a homogenous grazing area. The expert system is based on empirical knowledge consisting of hueristics, generalizations, assumptions, analogous procedures and judgments on the basis of human decision-making criteria. Simulation models are based on fundamental principles describing plant behavior. The models can be modified or replaced with more sophisticated models that might be available for a particular area of interest. Data pertaining to the data base include: the ecological status of a species, production class of species, preference class (palatability) as a function of season and phenological stage, defoliation threshold, phytomass loss through insect consumption as a function of season and phenological stage, disappearance of material through the natural phenological cycle as a function of season, unavailability of forage due to competition between feral and domesticated animals (i.e., percentage loss to feral animals in the presence and absence of domesticated animals), and animal consumption rates in kg/day. The minimum field work required before using the system is a survey of the management unit under consideration. Species encountered during the field survey are selected from the database and the percentage abundance is entered. Condition of the management unit is calculated by the condition assessment model. The user enters rainfall for the total growth season or specific season of interest. Total phytomass production that could be expected from the vegetation in the particular condition state is calculated by a production model based on rainfall and production indices of species. This value is presented to the user with options to either change the model or replace the calculated production result with one obtained from an external source. A series of accounting models are used for the calculation of the various components of phytomass loss or non-availability until the net phytomass available to the grazing animals is reached. The authors' state that an effective model dealing with the nature and interaction of these components as defined in this system could not be identified. If any particular value proves to be unsatisfactory, the user is allowed to substitute one from an outside source. After the completion of the calculations to determine the amount of effectively available phytomass, the grazing capacity of the management unit is calculated.

Study Methods

The following methods are those that were utilized during this study. The Methods section contains a more detailed description of the procedure for applying each method. These methods were chosen for study because they are promoted to grazing managers for use in the general vicinity of the study site, and they represent most of the fundamental approaches to stocking rate management.

Range Condition

The Range Condition method (Dyksterhuis 1949, USDA-SCS 1975, Ranching Systems Group 1993) is based on quantitative ecology. Management units are sampled by range site for vegetation species composition. A similarity index is calculated to compare current species composition of individual range sites with the composition of climax vegetation for the site. The similarity index represents the percentage of the original climax community remaining in the site. Each range site is designated into a condition class based on the percent similarity to climax vegetation. Condition classes have a corresponding initial stocking rate specific to each range site. Stocking rate is determined as the weighted mean of the stocking rates for the range sites contained in the management unit.

POPMIX

POPMIX (Ranching Systems Group 1993, Quirk 1995, Donges 1994) predicts the dietary composition for all kinds of animals that have access to a range site and, based on that, estimates the maximum stocking rate consistent with a user defined level of use of each forage species. Stocking rates for entire management units are calculated as a weighted mean of the stocking rates for the range sites contained therein. Inputs for POPMIX are vegetation species composition, estimated forage production, composition of kinds of animals using the management unit, and preference values of plant species or groups for each kind of animal. Preference values are: preferred, desirable, undesirable, nonconsumed, and toxic.

An estimate of the diet composition for each kind of animal is calculated by the diet selection algorithm. Nonconsummed and toxic species are not included in the diet composition. Dietary proportion of each undesirable species is predicted to be a positive exponential function of corresponding field composition. Dietary proportion of each desirable species is predicted to match its corresponding field proportion. Preferred forages are assumed to make up the remainder of the dietary composition. A stocking rate is then calculated by assigning available species dry matter, based on the estimated diet compositions, in proportions matching the user-defined demand ratios of kinds of animals utilizing the range site. Dry matter is assigned to herbivores until the user-defined use level is reached. A more comprehensive explanation may be found in Quirk 1995.

The Grazing Manager

The Grazing Manager (TGM) is decision support software designed to plan and monitor grazing management. TGM utilizes inputs concerning pasture resources and planned grazing demand to estimate projected forage use. Monthly observation and estimation of three variables; forage growth (relative to normal), animal demand, and actual forage use are used to make adjustments to annual carrying capacity as the year progresses.

Pasture resource inputs are: month that cumulative forage year begins, relative amounts of total annual forage growth occurring in each month (seasonality coefficients), average carrying capacity, and acres. Grazing demand inputs are animal unit equivalents (AUE) for classes of livestock, and dates of pasture use by class and number of livestock and amounts of supplemental feed.

Forage Survey

The Forage Survey method is outlined by White and Richardson (1991). Forage biomass is sampled at representative locations in each range site at the end of normal production cycles. Total pounds of forage per range site are estimated and these estimates are summed to arrive at the total pounds of forage for the entire pasture. This is then converted to Animal Unit Days (AUD) of grazing available. The procedures used to implement this method at the study site differ in some respects to the published method. Modifications to the method were made at the suggestion of Dr. White and an addition to the basic method was interjected in response to study site characteristics.

Evaluations and Comparisons of Methods

Published evaluations and/or comparisons of methods are limited. In Holechek and Pieper (1992) the authors purport that their analysis of a study involving two pastures in New Mexico indicates that on most western U.S. ranges the Holechek method, if modified to include only key forage species, will give a stocking rate that lies somewhere between destructive and very light. One pasture was in the Chihuahuan desert range type and the other was in a short-grass range type.

Holechek and Pieper (1992) compared stocking rates given by the Holechek method, the Soil Conservation Service (Range Condition method) and a modification of a procedure by Troxel and White (1989) against the actual long-term stocking rate applied at two different experimental ranges. The actual long term stocking rate is stated to have provided for range improvement over a period of years. No statistical analyses were used to compare methods.

The Troxel and White (1989) procedure as published is essentially the Forage

Survey method. Holechek and Pieper apparently modified the method by only estimating forage standing crop once, at the end of the summer growing season. Of this standing crop, the authors allocate 25% to livestock, 25% to diapearance (insects, wildlife, weathering), and 50% to site protection. It appears that after the modifications made by the authors, this method more closely resembles the method described by Merrill (1993). The authors also apply correction for distance from water and slope from Holechek (1988) to all methods.

According to the authors, the Troxel and White procedure (apparently modified) provided estimates, expressed as hectares per animal unit (year?), that were an average of 18% greater than the actual long-term stocking rates of 59.1 ha/AU for Chihuhuan desert and 24.3 ha/AU for Shortgrass. When adjustments for calf intake were applied the difference increased to 24%. It is important to note that the Troxel and White procedure as published provides a method for making seasonal adjustments to stocking rate and provides no information as to how it can be used to estimate long-term average stocking rate. Therefore it is unclear how the comparisons of this method and long-term actual stocking rates were made.

The Range Condition method estimated stocking rate of the Chihuahuan desert range type to be 44.5ha/AU, or 14.6 ha/AU less than the actual long-term stocking rate applied (59.1 ha/AU). However, on the short-grass range type it estimated stocking rate to be 35.3 ha/AU, or 11 ha/AU greater than the actual long-term stocking rate (24.3 ha/AU).

The Holechek method was applied using the following combinations of adjustments: calculations based only on the biomass of perennial forage species with no adjustment for calf intake; calculations based on the biomass of all forage species with no adjustment for calf intake; and calculations based on the biomass of all forage species with demand adjusted for intake by calves. The method consistently estimated stocking rate to be heavier than the actual long-term rates applied in all combinations reported except for when the method was applied to the Chihuahuan desert range with only perennial grass standing crop being used and no adjustments for calf intake applied.

Donges (1994) applied the Range Condition method and POPMIX concurrently to a study site. The results were not analyzed statistically; however, the author stated that he thought POPMIX produced the most accurate results. He felt that the range condition method may underestimate the carrying capacity since it does not take into account species that are not allowable in climax vegetation but are valuable forage plants.

Allen (1994) also applied the Range Condition method and POPMIX jointly to a study site. He stated, " In the opinion of this observer, the use of POPMIX to estimate stocking rate offers the most accurate idea of how many animals the area will carry in a sustainable manner". No analysis of the results was provided, nor were any reasons for this opinion stated.

Quirk (1995) tested the reliability of predictions of diet composition from POPMIX. Prediction of diet composition is central to the process by which POPMIX calculates stocking rate. Predicted and observed diet compositions for grazing paths were compared. Similarity between predicted and observed diet compositions was highly variable. In cases where field proportion of the preffered category was less than 5%, POPMIX predicted stocking rates to be extremely high (number of ha per animal unit), this led to a high degree of dissimilarity between stocking rate estimates.

Hyder (1953) conducted a study of herbage production and grazing capacity as related to range condition on an area of 4281 acres in south-eastern Oregon. The area had been stocked with cattle at a rate of 10 to 13 acres per animal unit month for 12 years previous. He states that although proper grazing capacity had been rated at 10 acres per animal unit month, a decline in range condition had been apparent. He mapped the area into three condition classes; 56% of the area was rated as being in poor condition, 41% was in fair condition, and 3% was in good condition. Herbage production was sampled on each condition class. The weighted average pounds of air dry herbage per acre was 139. He assumed that proper utilization would be 50% and that the daily ration per animal unit was 20 pounds of air dry herbage. Assuming this, he calculated that the total stocking rate for the entire area could be 496 animal unit months. He then states that if range deterioration had occurred during the previous 12 years with a stocking rate of 330 to 428 animal unit months, a serious error exists in the above procedure. He surmises that it may be more accurate to compute grazing capacity by assuming that 50% of the production of the good areas, equivalent to 160 lbs air dry herbage per acre, should remain after grazing. This amount should also be left on the areas in fair and poor condition if they are to be improved to good condition. However, if this is the case, then a deficit of 93,329 pounds of herbage exists and the area does not contain enough forage to allow grazing. He then states that if grazing could be limited to the fair and good areas, which have 195 and 322 lbs of air dry herbage per acre respectively as opposed to 88 on the poor area, there is adequate forage for 132 animal unit months.

Scanlan et.al. (1994) used their method to calculate carrying capacities for 45 properties based on resource information obtained from a survey. These calculated carrying capacities were then compared with graziers' estimates and with Queensland Department of Lands' ratings. The values calculated by the method and the graziers' estimates were highly correlated with a slope not significantly different from 1 ($p>0.1$). The rated carrying capacities were not correlated with either the calculated values or the graziers' estimates and were consistently lower.

Graham and Borth (1988) conducted a study to compare stocking levels assessed by range agrologists from the British Columbia Ministry of Forests and Lands with levels derived from a more formal planning procedure. The range agrologists determined stocking capacities based upon their knowledge and experience with each stock range. When rotational uses were defined and examined, the authors contend that optimal use patterns resulted in carrying capacities that were approximately double those of the agrologists.

MATERIALS AND METHODS

Study Site

Study data were collected on the Y Experimental Ranch (YER). The YER is located in the Rolling Plains of Texas approximately 30 kilometers east, southeast of the town of Paducah. Annual precipitation is highly varied with an average of approximately 634.5 mm. The average frost-free period is 220 days.

The study site consisted of 4 pastures on the southern end of the ranch. The 4 pastures contain a total of 6,075 hectares with an average size of 1,518 hectares. All pastures are entirely composed of native rangeland. Soils of the study site are very heterogeneous (Table 1. Soil taxonomy follows National Cooperative Soil Survey, U.S.A.).

Table 1. Soils (series and taxonomic class) Comprising the Study Site.

Series	Taxonomic Class
Acme	Loamy, mixed, thermic, shallow Entic Haplustolls
Aspermont	Fine-silty, mixed, thermic Typic Ustochrepts
Colorado	Fine-loamy, mixed, calcareous, thermic Typic Ustifluvents
Cottonwood	Loamy, mixed, calcareous, thermic, shallow Ustic Torriothents
Ector	Loamy-skeletal, carbonatic, thermic Lithic Calciustolls
Hollister	Fine, mixed, thermic Pachic Paleustolls
Knoco	Clayey, mixed, calcareous, thermic, shallow Ustic Torriorthents
Owens	Fine, mixed, thermic Typic Ustochrepts
Quanah	Fine-silty, mixed, thermic Typic Calciustolls
Sagerton	Fine, mixed, thermic Typic Argiustolls
Spur	Fine-loamy, mixed, thermic Fluventic Haplustolls
Talpa	Loamy, mixed, thermic lithic Calciustolls
Tillman	Fine, mixed, thermic Typic Paleustolls
Vernon	Fine, mixed, thermic Typic Ustochrepts
Westola	Coarse-loamy, mixed, calcareous, thermic Typic Ustifluvents
Weymouth	Fine-loamy, mixed, thermic Typic Ustochrepts

Vegetation of the YER is shrubland with mixed-grass understory. Dominant shrubs are honey mesquite (*Prosopis glandulosa*), redberry juniper (*Juniperous pinchotii*), and prickly pear (*Opuntia spp.*). Dominant grass species are buffalograss (*Buchloe dactyloides*), tobosa (*Hilaria mutica*), sideoats grama (*Boutelua curtipendula*), and hairy grama (*Boutelua hirsuta*). Dominant forbs are annuals, with common broomweed (*Amphiachyris dracunculoides*) being the most abundant.

Methods

Range Condition and POPMIX

Average carrying capacities of the study sites as computed by Range Condition and Popmix were taken from Donges (1994). These data were calculated from a baseline forage inventory of the entire YER during the summer of 1992 as a professional internship. The stated purpose of the inventory was to utilize methods which would be used by a working range manager or agency personnel to develop a baseline forage inventory in order to stock the ranch to a working level. The SCS National Range Handbook and advice from several range professionals were used as guides for choosing methods of collecting and evaluating data. Data were entered into Grazing Land Applications 2.0.1(GLA). GLA was used to calculate recommended stocking rates and carrying capacities by response unit, management unit (i.e., Pastures), and total ranch (Donges, 1994).

Species Composition

Vegetation of the study site was sampled for species composition during August of 1994 and August of 1995 and analyzed for repeatability. Sampling methods followed the

National Range Handbook (USDA-SCS, 1975) and advice given by R. Quiett (personal communication, 1994)[1]. Vegetation sampling was conducted for all major range sites in the 4 study pastures for 2 consecutive years along approximately the same transects.

A GIS map of the range sites on the YER was procured from Dr. W. R. Teague at the Texas Agricultural Experiment Station in Vernon, TX. Range sites were mapped for each pasture and area determined. Mr. R. Quiett of USDA-SCS assisted with ground truthing the range site map. Range sites that constituted only a small percentage of a pasture were treated as inclusions of a similar range site. One transect location per major range site was chosen on the map and then checked for suitability in the field. Transects were located in areas that represented average conditions for the range site as well as provided adequate space to place a long transect. Distance from water, topography, distance from roads, brush thickness, and proximity to winter feed grounds were all criteria that influenced transect placement.

Point of transect origin was marked with a steel fence post. Transect direction was chosen on the range site map and correlated to a compass reading. This compass reading was then used in the field to guide the direction of the transects. Every attempt was made to follow this compass reading in the field to ensure straight line transects. Unfortunately, thick brush often made strict adherence to the transect line impossible.

Different quadrat sizes were used to sample herbaceous and woody plant/cactus vegetation. Quadrats used to sample herbaceous vegetation were square (.73 x .73 m) and

[1] Reggie Quiett, Range Management Specialist, Natural Resources Conservation Service, Vernon, Texas.

were delineated on 3 sides by steel rebar. The fourth side was left open to facilitate placement at ground level under thick vegetation. Quadrats used to sample woody plants and cactus vegetation were square (3 x 3 m) and were formed by pacing off distances for sides and establishing corners from which ocular delineations were made. Plots were established at the point of the toe of the leading foot upon completion of each tenth pace. The bottom right corner of the herbaceous quadrat was placed at the point of plot establishment and aligned at a right angle to the transect line. The bottom left corner of the woody plant/cactus quadrat was placed at the point of plot establishment and the quadrat was aligned at a right angle to the transect line parallel to the herbaceous quadrat. A total of 10 herbaceous and woody plant/cactus quadrats were sampled. Pace length was approximately 1.4m.

Species within plots were estimated for fresh weight of standing crop. Double sampling was used to correct estimates of standing crop for herbaceous species. An assistant clipped and immediately weighed herbaceous species after they were estimated. Clipped weights were recorded to enable regression analysis. Clipped weights were converted to dry weight during analysis. To control bias, the estimator was not allowed access to clipped weights. Shrub, tree, and cactus were not clipped.

Weight-units were used to facilitate estimation of biomass. Weight-units are clipped samples of known fresh weight. A weight-unit was collected for each species encountered. Weight-units were kept as standards for use on subsequent plots and transects. Biomass was determined by estimating the number of weight-units per species occurring in the plot. During analysis, estimations by weight-unit were converted to grams.

Herbaceous quadrats were placed at ground level and all grass and forb species rooted within a quadrat were estimated for fresh weight of standing crop. Tree, shrub, and cacti species rooted within woody plant/cactus quadrats were estimated for fresh weight of current-year biomass production. Determining current-year biomass production proved difficult for several species. Perennial stems of tobosa grass create confusion between current and past year's production. Total above ground biomass was estimated and 30 percent was counted as current for use in species composition calculations. Evergreen species also posed a problem for estimating current-year production. Agarito (*Mahonia trifoliata*), Juniper, and Ephedra (*Ephedra pedunculata*) are evergreens encountered in transects. Standing crop was estimated as all green leaves and tender twigs and modified by the following proportions to arrive at current-year's production: 0.33 * standing crop of agarito, 0.143 * standing crop of juniper, 0.33 * standing crop of ephedra. Ten percent of estimated biomass of prickly pear was counted as current. Adjustments for these species were taken from Donges (1994).

Raw transect data were entered into a spreadsheet to calculate species composition per transect. Weight-units per species per transect were summed. Total grams fresh weight per species per transect was calculated by multiplying weight-unit standard by sum of weight-units per species per transect. Average weight per species was calculated and entered into a regression equation calculated using clipped fresh weights. Corrected average fresh weight per species was multiplied by dry matter percentages obtained from the National Range Handbook (USDA-SCS 1975). Average dry matter weight of species was multiplied by a conversion factor to obtain average pounds per acre dry matter. Percent growth complete and percent-ungrazed factors were used to adjust average pounds dry matter per acre for each species to average annual production per acre. Percent growth complete was obtained from growth curves for species (Donges 1994) (R.Quiett, personal communication, 1994)[1]. Percent ungrazed was obtained from estimates per species at time of sampling. Average annual dry matter production per species was divided by total average annual dry matter production to obtain percent composition per species.

Percent composition was compared to range site guides to obtain percent climax remaining per species. Percent climax remaining per species was summed to obtain a range condition score for each range site. Condition score was correlated to a condition class and a stocking rate range using range site guides. Interpolated stocking rates were calculated for each range site. The carrying capacity for each pasture was calculated as the weighted mean of the carrying capacities of all range sites in the pasture.

POPMIX was used to calculate a stocking rate from species composition data for all range sites for both years. Transect data were entered into GLA. Transects were individually attached to multi-species cases in the multi-species stocking calculator. Maximum harvest efficiency was left as the default value of 35%. Maximum undesirables in the diet was left as the default value of 15%. Cattle were selected as the animal kind and the ratio of livestock demand was set at 100%. Average AUE value was set at 1.0 and an averaged seasonal preference was selected.

Forage Survey

The study site contains large amounts of herbaceous biomass that is not normally consumed by livestock until other more palatable forage supplies have been exhuasted. It was hypothesized that use of the forage survey method as published could lead to a situation where the data suggested a large amount of grazing was still available in the pasture even though most of the herbage that is prefered or desired by livestock would have been already consumed. Therefore a modification to the forage survey method was devised and implemented along with the original forage survey method. Whereas the original forage survey method calls for the estimation of all herbaceous biomass, the modification only estimates biomass deemed to be prefered or desired by livestock. The methods are identical in all other respects. The Acronym TOTAL is used to designate the original forage survey method and the acronym FORAGE is used to designate the modification. Also, before sampling began, Dr. Larry White was consulted as to the proper method for using the forage survey method and at this time he suggested the use of threshold residue levels. The use of threshold residue levels is not mentioned in the forage survey manual.

Major range sites within study pastures were sampled for standing crop of forage dry matter (FORAGE) and total herbaceous dry matter (TOTAL) 3 times a year for 2 years. Animal demand, a threshold residue level, and standing crop of total herbaceous dry matter as well as forage dry matter were used to calculate animal unit days available. Procedure followed White and Richardson (1991) and advice from Dr. Larry White (personal communication, 1994)[2] .

The transect locations used for species composition sampling were also used for this method. Transect length and number of quadrats varied according to sample size calculations. Sampling was conducted at the end of normal forage cycles. August and late October- early November were determined to be the end of normal forage production cycles for the study site. A third forage survey was conducted in March to evaluate residual forage prior to initiation of rapid spring growth.

Grazable acres per range site were estimated by subtracting non-grazable acres from total acreage per range site. Non-grazable acres were determined from a GIS map and from observations in the pasture. The GIS map listed acreage by range sites of riverbeds and stock tanks. These were counted as ungrazeable. Field observations of impenetrable brush, large areas of gypsum soils devoid of vegetation, large rocks, and large patches of prickly pear cactus were counted as ungrazeable. A 100 pace transect was conducted for each range site in each pasture to help quantify ungrazable acreage.

Transects were sampled using a square quadrat (.73x.73 m) delineated on 3 sides by steel rebar. Quadrats were sampled every 10 paces. Quadrats were placed at ground level in position with the point of the toe of the leading foot. Pounds of dry matter standing crop (TOTAL) per acre were estimated for total herbaceous vegetation rooted within each plot. Pounds of forage standing crop dry matter (FORAGE) were then estimated. Decisions concerning what part of total biomass constituted forage were made based on cattle

[2] Dr. Larry White, Extension Range Specialist, Texas A&M University, College Station TX.

preference values for species (Donges 1994) and field experience.

At the beginning of each transect, 10 plots were estimated and required sample size was calculated. Total biomass estimates of the 10 plots were averaged. The range between the highest and lowest biomass estimates was calculated. The average for the 10 plots was divided by the range to arrive at the forage supply ratio. Total number of plots to sample was based on the forage supply ratio using a chart provided in White and Richardson (1991). Upon completion of sample size determination, additional plots were sampled as indicated.

Transects were sampled by an estimator and recorder. This was to facilitate the double sampling technique without biasing the estimator. A minimum of 10 estimated plots was clipped each day sampling was conducted. The recorder decided which plots would be clipped after the estimator had completed the estimate. Plots were clipped to ground line and separated into forage and non-forage if applicable. Clipped plots represented the range of standing crop encountered each day. Clipped vegetation was placed into labeled bags and oven-dried at a minimum of 60 degrees C for at least 24 h and then weighed to the nearest 0.01 g. Weights were converted to pounds per acre dry matter.

A regression equation was derived to predict clipped weight from estimates of forage standing crop. For each transect (i.e., range site), the average forage standing crop estimate was entered into the regression equation to arrive at a corrected average standing crop of forage in pounds per acre (FORAGE). A second regression equation was formulated using clipped weights of total herbaceous biomass and corresponding estimates

(TOTAL). This equation was used to convert average total biomass estimates per transect to corrected average standing crop of herbaceous biomass expressed as pounds per acre.

The Forage Survey method, as described by Dr. White, uses a threshold residual biomass level and an estimate of harvest efficiency to determine appropriate levels of grazing. The threshold residual biomass level is the amount to be left in the pasture to ensure longevity of forage species and proper watershed function. Suggested residue levels are as follows: short-grass, 300-500 lb/ac; mid-grass, 750-1000 lb/ac. To promote range improvement and reduce risk, the higher residue levels should be left for each category. To promote mid-grass over short-grass, mid-grass levels should be left to begin establishment of necessary microclimate (White, 1995).

The study site consisted of a mixture of mid-grass and short-grass. On many of the range sites, the preferred and desirable species for cattle were short-grasses while the mid-grasses were generally undesirable. This created confusion as to which residue level should be used. Since the majority of the forage grasses were short-grasses, it was decided that 500 lb/ac should be the target residue level.

The following formula was used to calculate total pounds forage available for grazing in each range site:

$$total\_pounds\_per\_range\_site = (SC - 500) * grazeable\_acres$$

where: *SC* is the average lb/ac of standing crop; *500* is the target residue level (lb/ac); and *grazable acres* is the number of acres in the range site available for grazing. Total pounds of each range site were summed by pasture to arrive at the total pounds of biomass available for grazing in each pasture. AUD available per pasture was calculated as follows:

$$AUD\_available = (Total\_per\_pasture * 0.5) / 26$$

where: *total per pasture* is the total pounds of biomass available for grazing; *0.5* is a harvest efficiency factor of 50%; and *26* is pounds of forage required for one AUD. SC values for both estimated forage and estimated total herbaceous biomass were used for each pasture to arrive at estimates of AUD available from forage and total herbaceous biomass. This procedure was repeated for all sampling dates.

The Grazing Manager

May was designated as the month that the cumulative forage year begins (Kothmann, personal communication, 1995)[3]. Forage green-up may begin earlier, but spring growth of cool-season forage does not cure and carry forward. Warm-season forage produced in May can be stockpiled for future use. Seasonality coefficients were chosen based on data compiled by Donges (1994) and were checked by field observations. Initial estimates of carrying capacity were based on the range condition estimates calculated in GLA as obtained from Donges (1994). Pasture acreages were obtained from a GIS map of the ranch.

AUE values were obtained from personal communications with Pinchak (1994,1995)[4] and Overton (1994,1995)[5]. Dates of livestock use by class and number of

[3] Dr. M.M. Kothmann, Texas A&M University, College Station, TX.
[4] Dr. Bill Pinchak, TAES, Vernon, TX.
[5] Mr. Neil Overton, Ranch Manager, Y Ranch, Paducah, TX.

head were obtained from the ranch manager (Overton, personal communication, 1994, 1995).

Monitoring data were gathered monthly with a few exceptions. Monthly forage adjustment factors were estimated based on rainfall and temperature data, pasture observations, and personal communication with the ranch manager (Overton, personal communication, 1994,1995). Monthly pasture use ratings were estimated using a scale adapted from Demming (1939) as presented in Kothmann and Hinnant (1994) (Table 2). Target use rating (TUR) was left at the default of 3. The target use rating is the pasture use rating that the manager wishes the pasture to have at the end of the grazing season. A TUR other than 3 will increase or decrease the animal unit days available in the pasture.

Table 2. Pasture Use Rating Scale.

USE RATING	CLASS	DESCRIPTION
0	Very Light	Little or no livestock use visible. Most plants appear to be ungrazed.
1	Light	Appears practically undisturbed when viewed obliquely. Only preferred areas and forage grazed. Many high choice plants are untouched and no use of less desirable plants
2	Moderate	Most accessible range shows grazing. Highest choice plants may be fully used, and the primary plants are supplying most of the forage used. Little or no use of poor forage. Little evidence of trailing to grazing.
3	Full	All accessible areas are grazed as uniformly as natural features and facilities will allow. Major sites have key forage species properly utilized. Little use of low-value species. A sufficient amount of the current year's growth of the primary species has been left to assure future maintenance. Overuse limited to between 5 and 10% of accessible areas. The objective is to assure that rangeland health is sustained.
4	Close	All accessible range plainly shows use and current year's growth of primary species is closely grazed. Livestock are forced to use some low-value forage species, considering seasonal preference.
5	Severe	Rangeland has mown or hedged appearance. Primary forage species almost completely used. Low-value forage shows considerable use and is carrying the grazing load.
6	Extreme	Range appears stripped of forage. All primary forage species and much poor quality forage grazed as closely as animals can bite it. Non-forage vegetation may remain and some very low value forage.

At the end of the first year, observed use ratings did not match use ratings calculated by TGM. If the calculated and estimated use ratings differ, inputs to the model must be adjusted to obtain calibration. Each input was evaluated based on available evidence starting with animal demand, seasonality, growth adjustments, and finally average carrying capacity. Average carrying capacity was modified using the following formula (Kothmann 1997):

$$ACC = OCC * PEUR * CACC * (CD*3)^{-1}$$

where:

ACC = Adjusted Carrying Capacity

OCC = Original Carrying Capacity

$PEUR$ = Pasture Estimated Use Rating

$CACC$ = Cumulative Actual Carrying Capacity

CD = Cumulative Demand

The adjusted carrying capacity was entered as the average carrying capacity for year 2. At the end of year 2 the average carrying capacity was again modified by the above formula.

Data Analysis

Average carrying capacities from Range Condition, Popmix, and TGM were evaluated using analysis of variance (ANOVA) procedures. The Forage Estimation method was excluded from this analysis because it does not provide an estimate of average carrying capacity. The ANOVA was computed for the following model:

$$y_{ij} = \mu + \pi_i + \nu_j + \epsilon_{ij} \ ; i = 1,2,3,4 \ \ j = 1,2,3,4 \qquad (1)$$

where:

y_{ij} = the average carrying capacity for the i^{th} pasture using j^{th} method,

μ = the overall mean average carrying capacity,

π_i = the effect on average carrying capacity due to pasture,

ν_j = the effect on average carrying capacity due to method,

ε_{ij} = the random error associated with y_{ij} (due to pasture × method interaction),

and the ε_{ij}'s are assumed to be iid $N(0, \sigma^2)$ random variables.

Annual carrying capacities from TGM, set at the default TUR of 3, the Forage Survey method (TOTAL), and the modification to the Forage Survey method (FORAGE) were evaluated using ANOVA. Annual carrying capacity was computed from TGM by converting the cumulative actual AUDs shown in the pasture summary report to ac/AUY. Annual carrying capacity was computed from TOTAL and FORAGE by adding the AUDs available from the March surveys to the AUDs of demand applied to the pasture up until that point and converting that sum to ac/AUY.

Replicate (1994 and 1995) observations permitted a preliminary investigation of whether a significant 'Pasture×Method' interaction was present in the data. Construction of the F statistic that tests for the presence of such an interaction requires the fitting of both a full model:

$$y_{ijk} = \mu + \pi_i + v_j + (\pi v)_{ij} + \varepsilon_{ijk} \quad ; \quad i = 1,2,3,4,\ j = 1,2,3,\ k = 1,2 \qquad (2)$$

and a reduced model:

$$y_{ijk} = \mu + \pi_i + v_j + \varepsilon_{ijk} \quad ; \quad i = 1,2,3,4,\ j = 1,2,3,\ k = 1,2 \qquad (3)$$

where:

y_{ijk} = the annual carrying capacity for the i^{th} pasture using j^{th} method in the k^{th} year,

μ = the overall mean annual carrying capacity,

π_i = the effect on annual carrying capacity due to pasture,

v_j = the effect on annual carrying capacity due to method,

$(\pi v)_{ij}$ = the effect of pasture interacting with method,

ε_{ijk} = the random error associated with y_{ijk},

and the ε_{ij}'s are assumed to be iid N (0, σ^2) random variables.

The null hypothesis that there was no pasture by method interaction was tested with the following test statistic:

$$F = ((SSR_2 - SSR_3) / (df_2 - df_3)) / MSE_2$$

where SSR_i = the sum of squares regression for model (i), i = 2,3; df_i = regression degrees of freedom for model (i), i = 2,3; and MSE_2 = the mean square error for model 2. The computed F statistic value was .0011426 which had a p-value of .50. Therefore, H_0 was not rejected, allowing the operating model to be the reduced model (3).

RESULTS AND DISCUSSION

Comparisons

Average Carrying Capacity

Average carrying capacities from TGM were computed at full use (TUR of 3) and moderate use (TUR of 2). Data for two years were available for TGM while only a single year of estimates were available for Range Condition and Popmix (Table 3).

Table 3. Average Carrying Capacities (ac/AUY)

Pasture	Methods					
	Range Condition	Popmix	TGM 94		TGM95	
			moderate	full	moderate	full
Love Creek	42.6	34	45.8	30.5	30	20
South Buffalo	53.2	68.1	53.3	35.5	41.6	27.7
Wild Horse	54.5	52.7	40.5	27	27.9	18.6
Wolf Creek	52.1	50.9	80.6	53.7	60.3	40.2

Average carrying capacities produced by TGM calculated at moderate use (TUR of 2) were compared with average carrying capacities produced by the range condition method and POPMIX in the first analysis. We first tested the null hypothesis that all pasture effects are identical and that all method effects are identical, i.e.,

$$H_0 : \pi_1 = \pi_2 = \pi_3 = \pi_4 \text{ and } \nu_1 = \nu_2 = \nu_3 = \nu_4$$

versus

$$H_1 : \text{not } H_0 .$$

The research hypothesis (H_1) is that either pasture effects differ or method effects differ (or both). The F statistic for testing H_0 against H_1 computed by the GLM procedure of SAS produced a p-value of 0.0993. This provides some evidence that H_0 is false. Components of the model (1) were then tested separately, i.e., F statistics were computed to test each of the hypotheses:

H_{A0}: All pasture effects are identical $\Leftrightarrow H_{0A}: \pi_1 = \pi_2 = \pi_3 = \pi_4$

$H_{B0:}$ All method effects are identical $\Leftrightarrow H_{0B}: \nu_1 = \nu_2 = \nu_3 = \nu_4$

The F statistic for testing H_{A0} had a p-value of 0.0573, providing evidence that all pasture effects are not identical. The p-value of the F statistic for testing H_{B0} was 0.2863, providing no evidence that method effects differ. Pair-wise comparisons between methods are reported in Table 4. A Bonferroni adjustment to the level of significance was used to interpret p-values (Neter et al.1990). Because six pair-wise comparisons are made, a p-value of 0.00833 ($\cong 0.05 \div 6$) or less would be required to conclude a significant difference exists between two methods. None of the comparisons differed significantly when the Bonferroni adjustment was made.

Table 4. Comparisons Between Average Carrying Capacities Produced by TGM at a TUR of 2(moderate use), Range Condition (RC), and POPMIX.

Comparison	p-value
TGM95 vs. RC	0.0322
TGM95 vs. POPMIX	0.0273
TGM94 vs. RC	0.0952
TGM94 vs. POPMIX	0.1072
POPMIX vs. RC	0.1526
TGM95 vs. TGM94	0.0128

Average carrying capacities produced by the range condition method are intended as guides to initial stocking rate. Modifications made by GLA to the range condition method are designed to further moderate the stocking rate suggestions. Average carrying capacities generated from TGM set at a TUR of 2 (moderate use) for both 1994 and 1995 did not differ significantly from average carrying capacities generated from the range condition method. This suggests that the range condition method and TGM produce similar estimates of moderate use.

No information was found pertaining to the question of whether POPMIX is intended to produce moderate or full use except that the maximum harvest efficiency default value is set at 35%. Average carrying capacities produced by POPMIX did not differ significantly from those produced by the range condition method or TGM set at a TUR of 2. This suggests that average carrying capacities produced by POPMIX are similar to the moderate use values produced by range condition and TGM.

Average carrying capacities produced by TGM calculated at full use (TUR of 3) were compared with average carrying capacities produced by the Range Condition method and POPMIX in the second analysis. Range Condition and POPMIX values were the same as in the first analysis. The same model (1) was employed in this second analysis. The null hypothesis tested was that all pasture effects are identical and that all method effects are identical.

$$H_0 : \pi_1 = \pi_2 = \pi_3 = \pi_4 \text{ and } \nu_1 = \nu_2 = \nu_3 = \nu_4$$

The computed F statistic had a p-value of 0.0105, providing strong evidence that H_0 is false. Components of the model (1) were then tested separately; i.e., F statistics were computed to test each of the hypotheses:

H_{A0}: All pasture effects are identical $\Leftrightarrow$ H_{0A}: $\pi_1 = \pi_2 = \pi_3 = \pi_4$

$H_{B0:}$ All method effects are identical $\Leftrightarrow$ H_{0B}: $\nu_1 = \nu_2 = \nu_3 = \nu_4$

The F statistic for testing H_{A0} had a p-value of 0.0636, providing some evidence that all pasture effects are not identical. The p-value of the F statistic for testing H_{B0} was 0.0067, providing strong evidence that method effects differ. Pair-wise comparisons between methods are reported in Table 5. A Bonferroni adjustment to the level of significance again was used to interpret p-values. With this adjustment all comparisons differed significantly at the 0.05 level.

Table 5. Comparisons Between Average Carrying Capacities Produced by TGM at a TUR of 3(full use), Range Condition (RC), and POPMIX.

Comparison	p-value
TGM95 vs. RC	0.0005
TGM95 vs. POPMIX	0.0004
TGM94 vs. RC	0.00745
TGM94 vs. POPMIX	0.00595

Average carrying capacities produced by TGM at a TUR of 3 (full use) were significantly different from average carrying capacities produced by both the range condition method and POPMIX. Increasing the TUR from 2 to 3 caused differences between TGM and the other methods to become significant, suggesting that full use as defined by TGM differs from carrying capacity estimates from range condition and POPMIX.

Annual carrying capacities (Table 6) from TGM (set at the default TUR of 3) and both the original (TOTAL) and modified (FORAGE) Forage Survey method were evaluated using ANOVA. The null

Table 6. Annual Carrying Capacities from TGM at a TUR of 3(full use), Forage Survey (TOTAL), and Forage Survey Modified (FORAGE).

	1994			1995		
Pasture	TGM	TOTAL	FORAGE	TGM	TOTAL	FORAGE
Love Creek	37	30	39	22	23	36
South Buffalo	43	19	32	30	21	36
Wild Horse	24	25	35	20	25	39
Wolf Creek	65	35	46	44	35	57

hypothesis we test first for the reduced model (3) is that all pasture effects are identical and that all method effects are identical, i.e.:

$$H_0: \pi_1 = \pi_2 = \pi_3 = \pi_4 \text{ and } \nu_1 = \nu_2 = \nu_3.$$

The research hypothesis (H_1) is that either pasture effects differ or method effects differ (or both). The computed F statistic had a p-value of 0.0004, providing very strong evidence for the rejection of H_0. Components of the model (3) were then tested separately; i.e., F statistics were computed to test each of the hypotheses:

$$H_{A0}\text{: All pasture effects are identical} \Leftrightarrow H_{0A}: \pi_1 = \pi_2 = \pi_3 = \pi_4$$

$$H_{B0}\text{: All method effects are identical} \Leftrightarrow H_{0B}: \nu_1 = \nu_2 = \nu_3.$$

The F statistic for testing H_{A0} had a p-value of 0.0008, providing strong evidence that pasture effects differ. The p-value of the F statistic for testing H_{B0} was 0.005, providing strong evidence that method effects differ. Pair-wise comparisons between methods are reported in Table 7. A Bonferroni adjustment to the level of significance again was used to interpret p-values. TGM and FORAGE were not significantly different. However, somewhat significant differences were found when TGM was compared to TOTAL (at the Bonferroni-adjusted 0.10 level = the 0.10÷3 level ≅ the 0.033 level) and when FORAGE was compared to TOTAL (at the Bonferroni-adjusted 0.01 level = the 0.01÷3 level ≅ the 0.0033 level)

Table 7. Comparisons Between Annual Carrying Capacities Produced from TGM at a TUR of 3(full use), Forage Survey (TOTAL), Forage Survey Modified (FORAGE).

Comparison	p-value
TGM vs. FORAGE	0.2386
TGM vs. TOTAL	0.0220
FORAGE vs. TOTAL	0.0015

Modification of the forage survey method caused significant differences in annual carrying capacities. Estimating only forage (FORAGE) compared to estimating total herbaceous standing crop (TOTAL) provided annual carrying capacities that were significantly different to the 0.01 level. Annual carrying capacities from TGM and FORAGE did not differ significantly. Annual carrying capacities from TGM and TOTAL differed significantly at the 0.10 level but not at the 0.05 level.

Repeatability

Estimates of average carrying capacity should be independent of year effects. Repeatability of data across 2 years from POPMIX, range condition, and TGM were evaluated for the purpose of ascertaining year effects. Data from POPMIX and range condition were deemed inappropriate for statistical analyses. The data from these methods are presented (Table 8 and Figure1) for visual inspection. Data from TGM were evaluated using ANOVA and reported in Table 3.

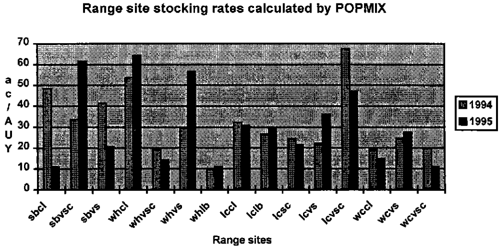
Table 8. Range Site Stocking Rates (ac/AUY) from POPMIX and Range Condition.

POPMIX

	Sbcl	sbvsc	sbvs	whcl	whvsc	whvs	whlb	lccl	lclb	lcsc	lcvs	lcvsc	wccl	wcvs	wcvsc
1994	48.55	33.58	41.63	53.71	19.06	29.29	9.87	32.25	26.51	24.46	22.15	67.47	18.97	24.61	19.78
1995	10.89	61.60	20.57	64.31	14.28	56.74	11.12	30.68	29.07	21.42	36.11	47.14	14.96	27.47	11.12

Range Condition

	Sbcl	sbvsc	sbvs	whcl	whvsc	whvs	whlb	lccl	lclb	lcsc	lcvs	lcvsc	wccl	wcvs	wcvs
1994	38.00	47.40	55.90	40.40	35.10	64.70	27.0	30.0	27.2	36.1	56.0	44.4	38.8	52.7	35.0
1995	35.8	42.5	48.4	40.5	37.9	46.7	30	46.9	30	34	55.6	36	38	40.4	34.3



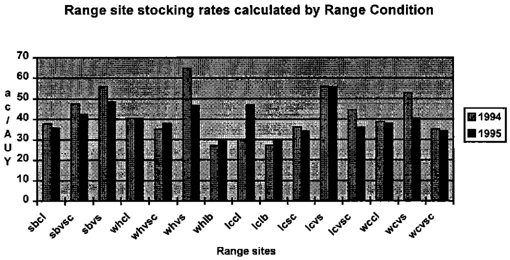


Figure 1. Graphical Representation of Range Site Stocking Rates (ac/AUY) from POPMIX and Range Condition.

Graphical representation of stocking rates by range site produced from POPMIX and range condition for 2 years showed no obvious patterns of year effects. Drastic variations are evident between years and methods for a few range sites. However, the source of this variation was not discernable from the data. Although average carrying capacities produced by TGM for 1994 and 1995 did not differ significantly, when the data are evaluated occularly (Table 3) there appears to be a year effect. The most likely explanation for this is error in estimating the monthly forage adjustment factor for the months of August and September in 1995. Precipitation during late August was much greater than normal, but the forage adjustment factors for August and September were estimated to be only slightly larger than normal. More frequent observation and greater experience of the operator might reduce this type of error.

Scope of Application

The use of range sites causes a problem for the universal application of Range Condition, POPMIX, and the Forage Survey methods. A soil survey of the application site is necessary to determine range sites. Not all areas have published soil surveys. A portion of the study site was in King County, for which no soil survey is available. Another characteristic of the Range Condition method that could limit its scope of application is pointed out by Holechek et al. (1989). They argue that finding representatives of climax vegetation for all range sites is difficult due to the fact that most rangelands have been disturbed to varying degrees. Range sites are used by the Forage Survey and POPMIX to determine homogeneous areas in which to sample. A soil survey is not as crucial to their use, however, because no information about the actual soils or climax vegetation is employed unless, in the case of POPMIX, data will be entered into GLA.

Ease of Use

One of the most important factors contributing to the ease of use of a method is the existence of a manual that presents the steps necessary for implementation in an understandable, informative, and complete manner. Range Condition is at a disadvantage because the method was designed for use by Soil Conservation Service (SCS) range technicians and its implementation has historically been provided by them. A manual designed for producers is not available. Range Condition based stocking rates can be calculated using GLA. However, data must have been gathered prior to the use of GLA and those procedures are not contained in the GLA manual. The manual does state that to make data entry easier, the following reference materials should be accessible: standard soil survey maps; National Range Handbook; Agricultural Handbook 296 for Major Land Resource Area (MLRA) information; USDA Soil Conservation Service National List of Scientific Plant Names, Vol.1; USDA Soil Conservation Service Study Guide, Conservation Planning for New Employees, Module 14, Rangeland; and National Research Council nutrient requirement manuals.

Instructions for the use of POPMIX are contained within the manual for GLA which can be obtained from the Ranching Systems Group, Texas A&M University. Instructions are detailed for all the steps after transect information is gathered. However, the subject of how to obtain transect information is not broached.

The Forage Survey method is described in White and Richardson (1991). This publication is in the form of a handout that may be obtained from the Texas Agricultural Extension Service. The method is presented in a step by step format with a list of materials needed, a photoguide, and example calculations. The method is presented clearly with the following possible exceptions. The term forage should be defined, the reader is unable to tell if it is meant to be all herbaceous biomass or just that which is normally consumed by livestock. The method includes instructions for making a photoguide. This may be necessary as the example photo guide lacks a high degree of clarity. The topic of regression may need to be discussed more due to the fact that it is not necessarily a common topic with grazing-land managers. The method requires a map of range sites but gives no indication as to how one should be obtained. Also, the manual uses stock units, which are based on energy requirements, to quantify available grazing and animal requirements. Stock units were apparently *en Vogue* at the time the manual was published but are no longer advocated by the author of the manual.

TGM is available from the Texas Agricultural Extension Service and a detailed manual is provided. The manual contains a step by step explanation of the implementation process as well as an example of output from the program. However, the formula for calculating the adjustment for carrying capacity is incorrect. Also, the following forage-related terms are used in the pasture use rating scale (Table 2) with out being defined in the manual and could lead to considerable confusion; preferred forage, high choice plants, less desirable plants, primary plants, poor forage, key forage species, low-value species, primary species, and non-forage.

Knowledge, Skills, and Abilities

The following discussion outlines some of the basic knowledge, specialized skills, and abilities that a user must posses to utilize various methods. However, deficiencies in any respect by a potential user do not necessarily preclude use of the method. All required knowledge skills and abilities may be learned as the method is implemented.

To use the range condition method, the forage survey method, or POPMIX a soils map must be obtained or else an alternative method of identifying range sites be found. The user must be able to delineate the boundaries of management units on the soil map and then identify the soils contained therein. Soils that characterize particular range sites must be grouped. The area contained in each range site must be measured. GLA further breaks down the pasture into response units; areas characterized by a particular combination of range site, and features that may limit use by livestock; i.e., distance from water, topography, and brush density. If the user wishes to use GLA for POPMIX or range condition, they must also locate all areas in the management unit that might be affected by factors that would limit livestock use by varying degrees. Area of these response units would then have to be ascertained.

Species composition sampling for range condition and POPMIX required in-depth knowledge of the characteristics of the flora contained in the management unit. All perennial species and many of the annuals encountered had to be identified down to the species level. Characteristics such as hairs and ligules were often necessary for identification depending on the condition of the plant. The ability to identify all species, even when grazed to within centimeters of the ground, took considerable time and effort. Unidentifiable specimens were routinely encountered in transects and had to be collected for later identification. Uncertainty still exists concerning many of the judgement calls. Numerous references had to be procured to aid in identification.

Sampling for POPMIX and range condition requires the ability to estimate biomass for all species. The ability to estimate percent of biomass already grazed is also needed. Extreme familiarity with locations within the pasture and/or detailed maps are essential for locating range sites (response units) and areas to sample (also feed grounds, bed grounds, water etc.). Plant growth cycles (production curves) must be known. All plant species encountered in POPMIX transects must be given seasonal preference values for all classes of herbivores with access to that particular range site. In-depth knowledge of the dietary preferences of these herbivores must be obtained through personal observation or by the use of experts or references.

The forage survey method requires the ability to estimate biomass with precision. Accuracy is not required because of the use of regression but is desirable. The ability to ascertain the preference of a species by herbivores is needed if the forage survey method is to be modified to estimate only forage species. The ability to calculate a regression equation and a fundamental understanding of its use is required.

TGM requires a computer and basic computer literacy skills. The user must be able to acquire information concerning pasture resources; seasonality coefficients, month forage growth begins, initial estimated carrying capacity, and planned grazing demand. The ability to keep records on livestock use by pasture throughout the year is also required. The ability to estimate monthly forage adjustment factors and pasture use ratings is essential and requires knowledge of the following factors; forage growth relative to normal by month, preferences for plant species and plant part by herbivores, spatial grazing patterns, and knowledge concerning plant species pertaining to proper use.

Discussion

As the methods were implemented they were evaluated for characteristics that potential users might deem important. Authorities on the use of each method were utilized to ensure proper implementation. However, at the time of implementation the author was a novice in the use of the methods and therefore may be able to provide some insight into their use that may not have been gained otherwise.

Time

The time it takes to implement each method depends on the particular set of circumstances encountered at each site. Resources available to the user and his or her particular base of existing experience are two important factors influencing time necessary for application. Although an effort was made to record the time required to implement each method it was deemed to be too subjective for inclusion. A potential user must review the requirements of each method and weigh them against their particular situation if an estimate of time is desired.

Forage Survey Method

Use of the forage survey method provides the opportunity to gain the ability to estimate standing crop. The most productive sites in a pasture as well as the most heavily utilized can be quantified. If the biomass estimates are modified to only include herbage considered to be forage the user also gains knowledge of the forage preference gradient.

The forage survey method, as outlined in the manual (i.e., without the use of threshold residue levels), provides no way to ascertain proper use. No matter how small an amount of biomass is estimated to be in the pasture, 25% is to be allocated for livestock use. If the standing crop of a pasture is estimated to be only 10 lb/acre, 2.5 lb/acre is still allocated for livestock use. The incorporation of threshold residue levels into the manual would provide a remedy.

In regards to threshold residue levels, a word of caution is in order. Several publications dealing with grazing management espouse the use of threshold residue levels for maintenance or improvement of the plant community and long term sustainability of production. The authors of these publications cite a similar set of studies as justification for their assertions concerning proper residue levels. However, the handful of repeatedly cited studies provides scant basis for any assumptions concerning proper residue levels for sustainability of all rangelands.

Range Condition and POPMIX

Vegetation sampling endows a manager with the ability to identify plant species with alacrity not provided by casual study. Sampling transects provides an opportunity to observe individual plant species at the micro level. It also encourages a manager to think about how much biomass has already been grazed off instead of just thinking about how much is left. Most importantly it stimulates contemplation concerning the present plant community and the potential plant community and possible methods of bringing the two closer.

Before sampling can be accomplished though, the management unit must be mapped according to range sites. The soils of this study site are highly varied (Table 1) and cause range site delineation to require considerable effort. Once the range sites are mapped the problem of finding them in the pasture then presents itself. Donges broaches this subject as well as other concerns relating to conducting his forage inventory.

The use of range sites by the range condition method, POPMIX, and the forage survey method raises another concern. These three methods attempt to quantify the amount of grazing provided by each range site as the basis for determining the amount in a pasture. However, depending on the range site composition, some range sites in certain pastures saw little livestock use. As an example, very shallow sites in the South Buffalo pasture were used sparingly by livestock even when most of the biomass of the other range sites had been utilized. To use the biomass of the very shallow sites to estimate grazing available in the pasture assumes that livestock will use these sites.

TGM

Forage use ratings proved to be difficult to estimate until certain characteristics of the study pastures and livestock behavior were learned. Plant identification skills and knowledge of seasonal livestock preferences for forage species as well as spatial use dynamics had to be acquired. The process of learning to estimate use ratings proved to be an excellent instructional exercise in the art of grazing management. Use ratings also foster the habit of contemplating forage supplies on a monthly basis. Whether or not use ratings are repeatable across observers is a consideration that needs to be investigated.

Much emphasis is placed on the process of estimating use ratings in the TGM manual. However, estimated monthly use ratings are not utilized by the program. They have no effect on the computer generated outcome. They are important to the user as an evaluation of whether the seasonality and growth adjustments may need changing. If the computer generated use ratings do not match the user-estimated ones, it may indicate problems with forage variables. Monthly forage adjustment factors are the input variable that has the greatest effect on the computer-generated output of the program. Comparatively little emphasis is placed on the process by which they are estimated. Estimation of these factors proved to be the most difficult as well as the most subjective process in TGM.

Adequacy of Representation

All of the methods rely on samples of some sort to give an indication of various properties of the pasture as a whole. How well those samples represent the actual conditions in the pasture is very important. The transects conducted for range condition and POPMIX are necessarily quite intensive and time consuming. This makes it difficult to apply them to as many areas as may need to be sampled. During the study, one transect (ten quadrats) was sampled in each range site that occurred in each pasture, for a total of 15 transects (150 quadrats). Even though it took two trained persons nearly two weeks to accomplish this, it still felt like it was a vastly inadequate number of samples. When the fact that the study site was 6,075 ha of extremely heterogeneous vegetation is considered, it seems apparent that the limited number of samples taken would hardly be enough to accurately describe the vegetation. Whether or not the samples taken were sufficient is unknown, however, to have increased the number of samples taken to a point where a degree of comfort in their adequacy was reached would have added an enormous amount of effort to what seemed at the time an already Herculean task. Donges (1994) also expresses concern with the number of samples he took and in a personal communication lamented that it would have taken many more samples to have reached a feeling of adequacy. In all fairness, it must be remembered that the conditions of the study site were so variable that vegetation could drastically change within a matter of meters. Finding a site where the soils and vegetation exhibited characteristics of a single range site for a large enough expanse to place a transect was often very difficult.

The forage survey method has a built in sample size calculation that caused sample sizes to range from 10 quadrats to well over a hundred on different range sites. Although this lent a greater feeling of security concerning adequacy of sampling, when the size of the pastures and their variability is taken into account it still seemed as though the sample was little more than a guess.

TGM makes no pretense of the input variables being samples. This may put the user a little more at ease with the foreknowledge that they are expected to make a guess, albeit, hopefully an educated one. This does not necessarily overcome the apprehension and consternation the user may feel when they are expected to reduce the grazing use displayed by the vegetation of highly variable, brush choked pasture that may be the equivalent in size to 10,000 American football fields into a single input variable. Making this decision becomes easier with practice, but true confidence is not approached until the user is familiar with all spacial and seasonal aspects of grazing in that pasture.

Management Implications

The range condition method will provide the user with an estimate of long-term average carrying capacity. It is not designed to do more than that. To arrive at this estimate requires a considerable amount of work using methods and concepts that a manager is probably not familiar with and for which no manual is available. However it has many other potential benefits where management is concerned. It encourages the user to become intimately familiar with the soils, range sites, and vegetation of the application site. A manager dealing with a property that is new to him/her may find it particularly useful. Most importantly, it familiarizes the user with what the species composition of the vegetation of a management unit may have once been and may be able to become again if managed properly. This can give clues as to past and future management and may provide incentive for management to improve.

POPMIX is very similar to the range condition method in regards to benefits and drawbacks. It provides the added benefit of encouraging the user to learn the grazing preferences of herbivores in regards to individual species across seasons. It does not necessarily familiarize the user with the vegetational community that may have been present prior to disturbance. Although it was not utilized for this purpose during this study, POPMIX is designed to allow a manager to arrive at an average carrying capacity in situations where several different types of herbivores are present. Both POPMIX and the range condition method provide no assistance in making decisions concerning stocking rate changes to meet varying levels of herbaceous production within or between years.

The forage survey method is specifically designed to allow a manager to ascertain the present level of grazing pressure and make adjustments based upon it. It provides no means for determining a long-term average carrying capacity. This would tend to limit its use to those managers that already have a reliable estimate of average carrying capacity. The process of estimating forage supplies can endow the user with the ability to gauge the amount of forage available and the length of time it will last under present grazing pressure. It should be remembered though that the method presented in the manual must be supplemented with extra information if it is to be useful.

TGM requires an initial estimate of average carrying capacity in order to initiate the program, but thereafter it provides an opportunity to asses the merit of this estimate and to modify it if necessary. Where TGM excels is in its ability to stimulate a manager to pay attention to the slight changes in grazing behavior that signal changes in the forage supply relative to demand. As an example, use of the program has the potential to cause a manager to become aware of the fact that livestock are gradually being forced to include more undesirable forage in their diet in order to make up their daily intake requirement. Being cognoscente of such changes in diet allows a manager to make necessary adjustments to demand in order to meet management goals. Like the forage survey method, TGM provide the user an opportunity to match livestock demand to fluctuating forage supplies. TGM requires computer literacy skills and a commitment to the practice of monthly estimation of often intangible input variables.

SUMMARY AND CONCLUSIONS

Selection and management of stocking rate is considered to be critically important to the management of grazing lands. Numerous methods have been devised to address stocking rate decisions. Methods vary in their approach and capabilities. Studies concerning the effect of long-term use of the methods were not found. Studies concerning comparisons between methods with respect to estimates of the same or similar parameters are scarce.

Study Methods

Average carrying capacities generated from TGM set at a TUR of 2 (moderate use) for both 1994 and 1995, average carrying capacities produced from the range condition method, and average carrying capacities produced by POPMIX did not differ significantly from each other. This suggests that the range condition method, and TGM produced similar estimates of moderate use. No information was found pertaining to the question of whether POPMIX is intended to produce moderate or full use except that the maximum harvest efficiency default value is set at 35%. Since average carrying capacities produced from all these methods did not differ significantly it suggests that average carrying capacities produced by POPMIX are similar to the moderate use values produced by range condition and TGM. Average carrying capacities produced by TGM at a TUR of 3 (full use) were significantly different from average carrying capacities produced by both the range condition method and POPMIX. The forage survey method does not provide an estimate of average carrying capacity.

Modification of the forage survey method caused significant differences in annual carrying capacities. Estimating only forage (FORAGE) compared to estimating total herbaceous standing crop (TOTAL) provided annual carrying capacities that were significantly different to the 0.01 level. Annual carrying capacities from TGM and FORAGE did not differ significantly. Annual carrying capacities from TGM and TOTAL differed significantly at the 0.10 level but not at the 0.05 level.

Graphical representation of stocking rates by range site produced from POPMIX and the range condition method for two years showed no obvious patterns of year effect. Drastic variations are evident between years and methods for a few range sites. Average carrying capacities from TGM for two years did not differ significantly. However, when the data are examined, there is an evident year effect. This error is most likely due to estimation of input variables. Error such as this highlights the subjective nature of some of the input variables in TGM.

The use of range sites and climax community poses a limitation on the universal application of the range condition method. POPMIX and the forage survey method are similarly constrained by the use of range sites but can be adapted for universal application easier since they do not rely on an estimate of climax community. TGM does not appear to be limited in its scope of application.

Range condition was designed for use by SCS range conservationists and its use is limited by the lack of a manual published explicitly for grazing-land managers.

Instructions for the use of POPMIX are detailed for all of the steps after transect information has been gathered, but they do not broach the subject of how to obtain these input variables. A fairly detailed manual and an example photoguide are available for the forage survey method. However, this manual contains out-moded methods, vague terminology, and provides no way to ascertain proper use. The manual for TGM covers data collection, input, and evaluation. Failure to adequately explain the method for estimating forage adjustment factors makes reliable estimation of this important variable difficult. Lack of a glossary and an error in a formula also detract from its usability.

The range condition method, the forage survey method, and POPMIX require that the management unit be mapped by range site and these acreages calculated. Species composition sampling for range condition and POPMIX requires in-depth knowledge of floral characteristics. Sampling for POPMIX and range condition requires the ability to estimate biomass and percent grazed on a species basis. POPMIX requires knowledge of seasonal preference values for all plant species. The forage survey requires consistency of biomass estimation and the ability to calculate a regression equation. TGM requires basic computer literacy skills. Information concerning numerous pasture resources must be acquired. Livestock numbers, estimates of forage growth adjustment factors, and forage use ratings must be collected on a monthly basis.

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