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—*to develop an understanding of range ecosystems and of the principles applicable to the management of range resources;*

—*to assist all who work with range resources to keep abreast of new findings and techniques in the science and art of range management;*

—*to improve the effectiveness of range management to obtain from range resources the products and values necessary for man's welfare;*

—*to create a public appreciation of the economic and social benefits to be obtained from the range environment;*

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Vegetation and water yield dynamics in an Edwards Plateau watershed

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Abstract

Woody cover, when expressed at the scale of the 207 km^2 Cusenbary Draw basin, remained unchanged (~23%) from 1955 to 1990. When expressed at the scale of range sites, woody cover declined on sites with relatively high production potential and increased on sites with relatively low production potential. Change in woody cover distribution at sub-range site scales, increased low and high woody covers and decreased intermediate woody cover, would be expected to lead to increased water yield at the basin scale because there was an apparent threshold woody cover (~20%) above which simulated evapotranspiration (ET) changed little with increasing woody cover. This potential increase, however, was more than offset by the decreased water yield due to increased ET loss associated with compositional changes of woody vegetation from oak to juniper. A set of woody cover-ET regression curves was developed for different range sites based on simulation studies using the SPUR-91 hydrologic model. Based on these woody cover-ET regression curves and GIS analysis, no brush management would result in a 35% decrease in water yield, while a hypothetical brush management cost-share program would increase water yield by 43% over the 1990 level. Benefits in water yield and forage production from brush management differ in different range sites. A brush management cost-share program that preferentially allocated brush management to sites with deep soil and the highest forage production potential increased water yield by 50%, compared to a 100% increase if brush management were preferentially allocated on sites with shallow soil and highest water yield potential. These model results illustrate that the spatial scale of assessment and spatial distribution of brush management among range sites should be important concerns associated with developing and evaluating brush management policies.

Key Words: brush management, evapotranspiration, GIS and remote sensing, hydrologic modeling, semi-arid rangeland

Resumen

Cuando la cobertura de la vegetación leñosa se expresó a escala de los 207 km^2 de la cuenca Cusenbary Draw permaneció sin cambios (~23%) durante el periodo de 1955 a 1990. Cuando se expresó a escala de sitio de pastizal, la cobertura de leñosas disminuyó en sitios con potenciales de producción relativamente altos y se incrementó en sitios con potenciales de producción relativamente bajos. Por los cambios en la distribución de la cobertura de leñosas a escala de subsitio de pastizal (aumento en la cobertura de leñosas bajas y altas y disminución en la de leñosas intermedias) se esperaría que ocurriera un aumento en el rendimiento de agua a nivel de cuenca, porque aparentemente hubo un umbral de cobertura de leñosas (~20%) arriba del cual la evapotranspiración simulada (ET) cambia poco con los aumentos de cobertura de leñosas. Sin embargo, este incremento potencial fue mas que compensado por la disminución en el rendimiento de agua debido a el incremento de la perdida de ET asociada con los cambios composicionales de la vegetación leñosas de roble a juniper. Se desarrollo un juego de curvas de regresión entre coberturas de leñosas y ET para diferentes sitios de pastizal, las curvas se desarrollaron en base a estudios de simulación utilizando el modelo hidrológico SPUR-91. Basados en estas curvas de regresión y análisis con sistemas de información geográfica, el no manejar la vegetación arbustiva resultaría en una disminución del 35% del rendimiento de agua, mientras que un programa de manejo de los arbustos, hipotéticamente viable en términos de costos, incrementaría el rendimiento de agua en 43% respecto a la producción de 1990. Los beneficios en rendimiento de agua y producción de forraje difieren entre sitios de pastizal distintos. Un programa de manejo de arbustos económicamente viable asignado a sitios de pastizal con suelo profundo y la mas alta de producción de forraje incrementaría el rendimiento de agua en 50%, comparado con el incremento del 100% si el manejo de arbustos se asignará a sitios con suelos poco profundos y con el mayor potencial de rendimiento de agua. Los resultados de este modelo ilustran que la evaluación de la escala espacial y la distribución espacial del manejo de arbustos entre sitios de pastizal deben ser preocupaciones importantes asociadas al desarrollo y evaluación de las políticas de manejo de arbustos.

Replacement of grasslands and savannas with woodlands is a worldwide trend that coincided with European expansion and settlement in the eighteenth and nineteenth centuries (Scholes and Archer 1997). This shift from grassland savannas to shrub-dominated landscapes has broad implications for availability and quality of water (Archer 1994, Thurow 1998). Increased woody cover and its effect on hydrology have special significance in the semiarid rangelands of the western US that are relied on as sources of

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water, such as the Edwards Plateau region of Texas. The Edwards aquifer, which is recharged from Edwards Plateau rangelands, is the primary source of water for San Antonio, Austin and the many other municipalities of the region. Many rivers also originate in this region, which provide habitat for endangered species, recreational opportunities, and water supply to an area extending from the Edwards Plateau to the Gulf Coast.

Policy makers are increasingly concerned that vegetation management on rangeland be responsive to regional water yield objectives (Thurow et al. 2000). Water yield (deep percolation and surface runoff) from rangelands can be determined by the balance of water input in precipitation and water output in evapotranspiration (interception loss, soil evaporation, and transpiration), plus any changes in the amount of water stored in soil (Hibbert 1983). In semi-arid rangelands, evapotranspiration (ET) can account for 80–95% of the water loss (Thurow 1991). Changes in woody cover in semi-arid rangelands can significantly alter ET losses, hence water yield, due to higher interception and transpiration of woody vegetation compared to those of herbaceous vegetation, particularly on shallow range sites. Annual interception loss, mainly determined by precipitation pattern and the water holding capacity of plant canopies and associated litter, ranges from 11 to 18% of precipitation for herbaceous vegetation (Clark 1940, Thurow et al. 1987) and is considerably higher for woody vegetation [e.g., about 46% for live oak (Thurow et al. 1987) and 70 to 80% for juniper (Eddleman 1983, Hester 1996)]. Most woody plants in semi-arid rangelands also have higher transpiration rates than do grasses and forbs due to larger transpirational area (leaf area), longer transpirational period (length of growing period), and deeper rooting structures that access deep soil moisture (Davis and Pase 1977, West 1992). Studies at plot (1 to 20 m^2) and catchment (1 to 10 ha) scales have shown that reduction of woody cover through brush management on the Edwards Plateau area significantly increases water yield, mostly as deep drainage to recharge springs and aquifers because of the high infiltration characteristics of Edwards Plateau soils and the fractured limestone substrate (Richardson et al. 1979, Dugas et al. 1996, Thurow and Hester 1997).

A number of catchment experiments have been conducted on rangeland and forest watersheds to determine the effect of vegetation changes on ET and water yield (summarized by Bosch and Hewlett 1982, Hibbert 1983, Douglass 1983). Catchment level water yield studies are very expensive and frequently require many years before a conclusion can be drawn, consequently empirical studies can only evaluate a very limited number of sites and vegetation management scenarios. A potentially effective approach for assessing the effect of brush management on water yield in large watersheds is computer simulation using watershed hydrologic models (Singh 1995). One such model is the SPUR-91 (Simulation of Production and Utilization of Rangelands), a physically-based simulation model that has been specifically developed and validated for rangeland ecosystems (Wight and Skiles 1987, Carlson and Thurow 1992, 1996). One limiting factor for this approach is the requirement of complex input parameters of spatially distributed attributes. The development of geographic information systems (GIS) technology and spatial modeling approaches in the recent decades has significantly eased this limitation and made the application of complex hydrology models practical (Maidment 1993). Another factor that limits the usefulness of hydrologic modeling approaches for assessment of the effects of brush management on water yield is spatially explicit vegetation data with sufficient spatial resolution and extent suitable for both brush management assessment and hydrologic modeling. Remote sensing and digital image processing technologies have made the development of such vegetation data covering large spatial and temporal extents possible, although it requires a considerable amount of time and effort.

Objectives of this study were to 1) assess historical (1955 to 1990) changes in vegetation structure and its relationship to rangeland management, using remote sensing and GIS analysis, in a 207 km^2 watershed composed of 5 range sites representative of the rangelands on the western Edwards Plateau, and 2) develop predictive vegetation structure and water yield relationships using SPUR-91 hydrologic model simulations and GIS modeling to evaluate a) the effect of changing woody cover, as well as the spatial scale of assessment, on water yield, and b) the water yield ramifications of brush management patterns and policies.

Materials and Methods

Study Area and GIS Database

The study was conducted on the Cusenbary Draw basin (207 km^2) on the Edwards Plateau (30°21' N; 100°38' W) (Fig. 1). The elevation of the basin ranges from 628 to 711 m above msl. The mean frost-free period is 240 days. Annual precipitation is highly variable with a mean of 553 mm and a range of 156–1,054 mm. Most precipitation results from intense, brief thunderstorms. Low Stony Hill and Shallow range sites are the most common range sites within the basin; Deep Divide, Valley and Bottomland range sites are also present (Fig. 1). Tarrant stony clay,

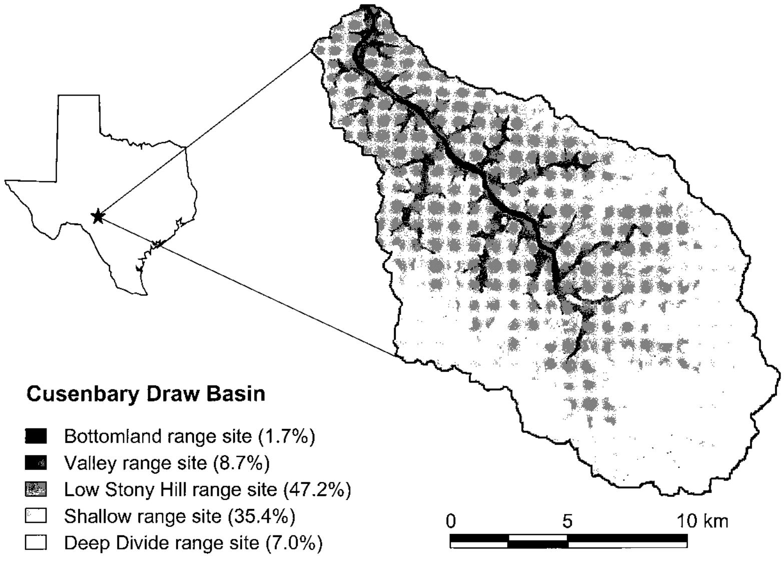

Fig. 1. Study site showing the location of the Cusenbary Draw basin and range sites in the basin. Percentage in parentheses indicates proportion of the basin in a range site.

Kavett-Tarrant complex, Tobosa clay, Knippa silty clay and the Frio-Dev association characterize the soils within these range sites, respectively (Wiedenfeld and McAndrew 1968). Woody vegetation composition varies considerably among sites. Ashe and redberry juniper (*Juniperus ashei* Buchh. and *Juniperus pinchotii* Sudw.), live oak (*Quercus virginiana* Mill.), and Vasey shin oak (*Q. pungens* var. *vaseyana* Buckholz) dominate the shallow soil upland sites with honey mesquite (*Prosopis glandulosa* Torr.) and live oak dominating the sites with deeper soil. Dominant herbaceous species include Texas wintergrass (*Stipa leucotricha* Trin. & Rupr.), sideoats grama (*Bouteloua curtipendula* Torr.), three-awn (*Aristida purpurea* Nutt.), and common curlymesquite (*Hilaria belangeri* Nash) (Fuhlendorf and Smeins 1997).

A GIS database was developed for the study area. The watershed boundaries of the Cusenbary Draw basin and its sub-watersheds were delineated based on the 1:24000 digital elevation models (DEM) through cell-based hydrologic modeling using ARC/INFO GRID (ESRI 1994). Over 300 ground control points were distributed throughout the basin and immediate surrounding areas; geo-location data for these points were collected using Trimble's Pathfinder global positioning system (GPS) units (±2.5-m accuracy). Range sites were delineated from 1:20000 NRCS soils maps from the Sutton County Soil Survey (Wiedenfeld and McAndrew 1968). These soils maps were scanned into digital format, mosaicked using ERDAS Imagine (ERDAS 1997), and geo-referenced with the GPS control points using a second-order polynomial transformation (Fig. 1).

Changes in Vegetation Structure

Historical vegetation coverage was developed from over 90 black and white aerial photographs taken in 1955 (1:20,000) and 1990 (1:40,000). The photos were scanned into digital form with 1-m resolution (1-m^2 pixels); mosaicked and geo-referenced based on GPS ground control points using ERDAS Imagine. An iterative self-organizing clustering algorithm (ERDAS ISODATA) (ERDAS 1997) was used to classify the images by range site. Fifty clusters generated by the algorithm were then reclassified into 2 classes, woody and non-woody, based on original aerial photographs and field verification. A 50x50-m moving window with 10-m steps was used to evaluate the spatial distribution of woody cover in different range sites. The composition of the vegetation in each range site was estimated based on data from the literature (Smeins and Merrill 1988, Wiedenfeld and McAndrew 1968, Thurow et al. 1988, Schacht and Reinke 1993, Hester 1996). Seven compositional classes including juniper, oak, mesquite, short-grass, midgrass, forbs, and bare ground were used for simulation modeling.

Effect of Woody Cover on Water Yield

The effects of woody cover on water yield were examined through simulations using the SPUR-91 hydrologic model (Carlson and Thurow 1992). This model was validated on several Texas rangeland sites, including the Sonora Agricultural Experiment Station site which was part of the Cusenbary Draw basin. The model has proven to be effective in predicting the effect of management practices on hydrology (Carlson and Thurow 1996). A single climate input file, generated based on average monthly precipitation data (1948 to 1996), was used for all simulations. The generated precipitation data were adjusted by subtracting interception that was determined based on the percent cover and species composition of the vegetation in each range site and the species-specific interception data from the literature (Clark 1940, Thurow et al. 1987, Desai 1992, Thurow and Hester 1997) since SPUR-91 did not take interception into account. The phytomass for each site was estimated based on the vegetation composition and species-specific phytomass parameters from the SPUR-91 Texas validation input files (Carlson and Thurow 1992). Simulations were conducted for nine ~10% increments from 0 to 80% of potential woody cover for each of the range sites based on 1990 species composition (Fuhlendorf and Smeins 1997, Unpublished data, Smeins and Fuhlendorf). The species compositions was defined by the proportion of woody cover that were juniper, oaks, and mesquite and the proportion of non-woody cover that were short-grass, mid-grass, forbs, and bare ground for each of the range sites (Redeker 1998). These compositions were used for simulations with different percent woody cover. Each simulation was run for 15 years and only the last 10 years of data were used for analysis, which increases the reliability of simulation results by allowing the sensitive parameters to stabilize (Carlson and Thurow 1992). Results of the simulations for the nine, 0 to 80% woody cover levels, were used to generate regression curves of percent woody cover vs. ET for each of the range sites. A form of exponential curve was fitted to the data with non-linear regression using the Levenberg-Marquardt algorithm. Evapotranspiration for each range site was estimated based on the proportions of land (in 0.25 ha cells) in 5% woody cover intervals and the woody cover-ET curve for that range site. The ET for the entire basin was determined as a weighted average of the range site estimates. Running the simulation by range site using the field scale model may underestimate the ET for the Valley and Bottomland range sites because there may be additional water input from surface and subsurface flows from the upland sites. Given the shallow soil and fractured limestone substrate of the uplands, however, it is likely that the majority of the water input from upland would be in channel, and possibly spring, flow which may affect only a limited proportion of the Valley and Bottomland range sites. Water yield was estimated as the difference between simulated annual precipitation and predicted total ET, assuming no long-term changes in water stored in soil. Although changes in water stored in soil (ΔS) can be an important factor for event-based simulation and time specific short-term evaluations, in assessing long-term average behavior for strategic evaluation and planning, however, it should be reasonable to assume $\Delta S=0$.

Water Yield Ramifications of Brush Management

The woody cover-ET regression curves were used to assess the effect of vegetation on water yield under different management scenarios. For a scenario of zero brush management, 2 areas in the basin that received no brush management from 1955 to 1990, one on a deep soil range site and the other on a shallow soil range site, were used to estimate the relative change in percent woody cover in the absence of brush management. The relative change in woody cover of the deep range site was used for the Bottomland, Valley and Deep Divide range sites where the primary invading species is honey mesquite. The relative change in woody cover of the shallow site was used for the Shallow and Low Stony Hill range sites where the primary invading species is juniper. In the second scenario, the effects of a Texas brush management program that incorporated a revenue neutral cost-share offer (Thurow et al. 2000) were examined. This study found that 40% of the rangeland would be voluntarily enrolled in a publicly funded brush management program designed to increase water yield that required that woody cover be reduced to 3% via chaining on all land entered into the program. For this simulation, woody cover was reduced to 3% on 40% of the land in each range site, and was held at the 1990 level in the remaining 60% of the land. The third and fourth scenarios were variations of the second scenario with different spatial distributions of the enrolled land; one concentrated the brush management on the range sites that had the greatest potential for forage production and the other concentrated the brush management on the range sites that had the greatest potential for water yield.

Results and Discussions

Changes in Vegetation Structure

The overall woody cover remained virtually unchanged (23.6%), when expressed at the scale of the 207 km^2 Cusenbary Draw basin. However, changes in woody cover varied considerably among different range sites over the 35 years based on the classified 1955 and 1990 aerial photography (Fig. 2). This is largely due to the uneven distribution of brush management efforts (Redeker et al. 1998). The majority of the brush management took place on range sites with higher production potential because investment in clearing brush on these sites offers higher economic returns in terms of increases in forage. As a result, woody cover decreased 17% and 28%, respectively, in the most productive Bottomland and Valley range sites while it increased over 170% in the least productive Deep Divide sites.

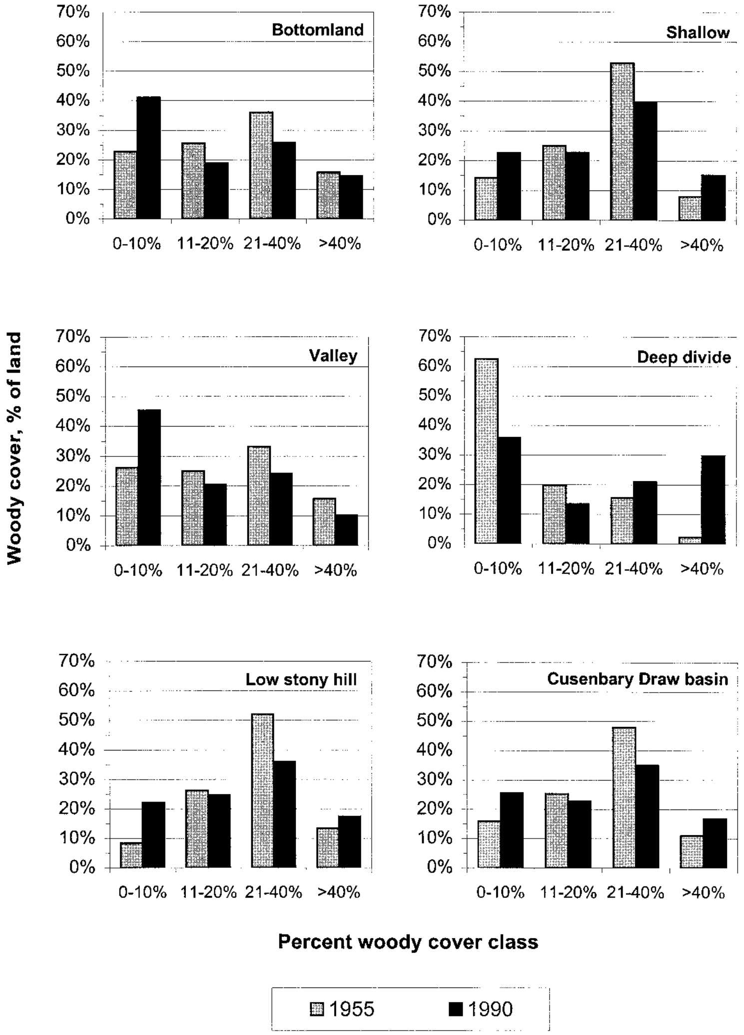

Fig. 3. Distribution of areas with different percent woody cover for individual range site and the whole basin in 1955 and 1990.

Changes in the relative amount of land with different amount of woody cover in each range site further illustrate the dynamics in woody encroachment and brush management (Fig. 3). On the most productive Bottomland and Valley range sites, considerable amount of land with medium (11–40%) and high (>40%) woody covers were converted to areas with low woody cover (≤10%). The proportion of land with low woody cover on these range sites increased to over 40% by 1990, some 70 to 80% increase over the 35 years. On Low Stony Hill and Shallow range sites with intermediate forage production potentials, considerable brush management increased the proportion of land with low woody cover to over 20%; however, woody encroachment in some other areas was not controlled which resulted in an increase in the area of land with high woody cover. Due to low levels

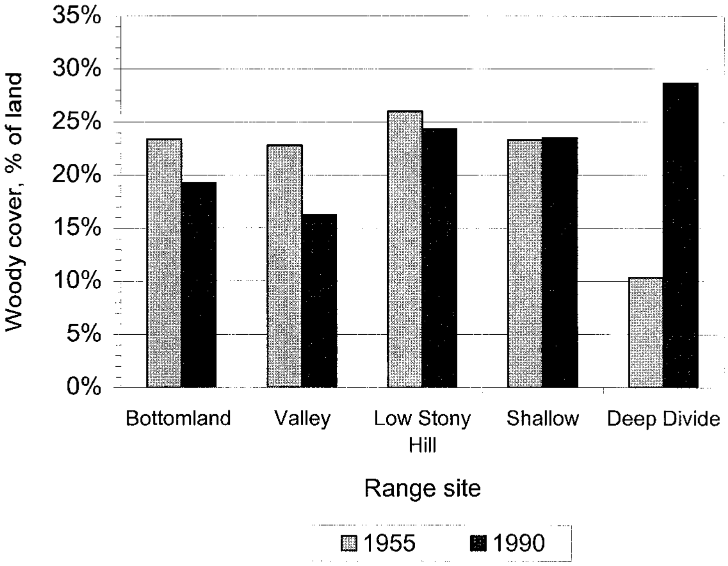

Fig. 2. Percent cover of woody vegetation for individual range site in 1955 and 1990.

of brush management efforts, the area with low woody cover decreased from 62% to 36% for the least productive Deep Divide range site, while the area with high woody cover increased from less than 3% to near 30%. As a result of these changes, there was an increase in the amount of land with either low or high woody cover at the expense of a decreasing amount of land with intermediate woody cover in the Cusenbary Draw basin as a whole. This change in the distribution reflected a combination of accelerated rates of woody encroachment and unevenly distributed brush management efforts.

Although the vegetation composition on the deeper range sites remained unchanged over the 35 years, there was a significant reciprocal change in juniper and oak cover on the Low Stony Hill and Shallow range sites. Juniper cover increased from 2.9% in 1955 to 10.9% in 1990, while oak cover decreased from 18.3% to 9.9% in the same period. Two factors contributed most to this shift in woody vegetation structure. The severe drought in the 1950's resulted in high mortalities of woody species, but the mortality for juniper trees less than 2-m tall was insignificant (Merrill and Young 1959). This set the stage for juniper to increase its cover in the years after the drought with the absence of fire (Fuhlendorf et al. 1996). The other factor contributing to this increase in juniper was the chaining practices common in the 1950's and 1960's that indiscriminately cleared all brush. Redberry juniper aggressively coppices from the roots. It is likely that the continuous presence of cattle, sheep, goats and deer would have put greater browse pressure on the resprouts and seedlings of oaks than on the less palatable juniper seedlings and resprouts.

Effect of Woody Cover on Water Yield

Woody Cover-ET Relationship

The woody cover-ET regression curves based on the systematic simulation studies represent the effect of woody cover on water balance for each of the 5 range sites within the Cusenbary Draw basin which are representative of the rangelands on the Edwards Plateau (Fig. 4). Evapotranspiration, the reciprocal of water yield, often accounts for over 90–95% of the water budget on these rangelands and the reduction of ET is the key for vegetation management to increase water yield (runoff and deep percolation). Deeper range sites (Bottomland and Valley) exhibit relatively little change in ET with changes in woody cover. This is due to the high ET at 0% woody cover determined by the soil depth and large amount of herbaceous transpiring tissue, and the low interception losses associated with honey mesquite which tends to dominate these sites. On the Low Stony Hill and Shallow range sites, ET increases dramatically with increase in woody cover over 0% as a result of elevated interception loss of precipitation by juniper and oak. With continuous deep soil, relatively high herbaceous cover and greater component of mesquite in the woody cover, the upland Deep Divide range sites have relatively small change in ET with changes in woody cover.

These simulation results compared favorably with the literature. The model predicted ET losses within 5% of values reported in the studies of Thurow and Hester (1997) based on empirical field studies conducted on a Shallow range site at the Sonora Agriculture Experiment Station. The simulation results fit well to the experimental studies not only at 0% woody cover, where very high reliability was demonstrated in the validation studies (Carlson and Thurow 1992), but also at high woody cover levels. The SPUR-91 model simulations predicted 5% greater ET than the empirical estimates on 100% herbaceous cover, 2% greater on 30% woody cover and less than 1% greater on 60% woody cover. These similar results of 2 very different methods strengthen the case that these estimates are reasonable for the region.

The simulations, however, apparently over-predict ET at low but non-zero woody cover levels. The SPUR-91 model performs well in situations with no (0%)

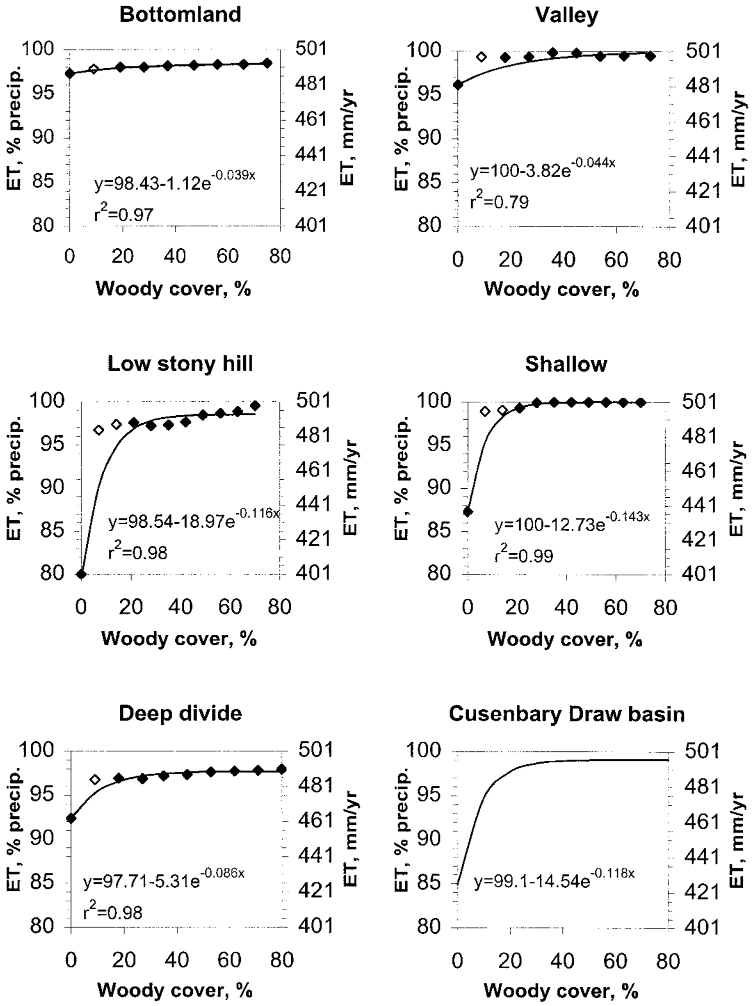

Fig. 4. Relationship between evapotranspiration (ET, expressed as a percent of precipitation) and percent woody cover at different range sites and for the Cusenbary Draw basin as a whole. The symbols shown are SPUR 91 simulation results and the line is the regression curve. The open symbols represent data points that were not used in the regression for reasons detailed in the text.

woody cover or with relatively high (>20%) woody cover, but not in situations with relatively low (<20%) woody cover. The soil moisture extraction routine of the model allows plants to extract their physiologic requirements of water before allowing soil water to percolate below their rooting zone. When a single woody plant is present on a site the model does not limit water extraction for that plant to the volume of soil physically accessible to the plant. Rather this plant is allowed unlimited access to all soil water on the site that has percolated below the maximum rooting depth of more shallow rooted herbaceous species. This lack of spatial constraints on soil water available for individual woody plants allows unrealistic luxury consumption that results in an over-prediction of transpiration in low woody cover scenarios. This over-prediction in low woody cover conditions can be compensated for by fitting a form of exponential curves to the data points generated by the model, excluding the data points at very low (<15%) but non-zero woody covers. These regression curves fit the data points at 0% and high woody cover well while reducing the effects of excessive water extraction in low woody cover conditions. An ET to woody cover regression curve for the Cusenbary Draw basin was generated based on the regression curves for individual range sites and the relative proportions of the basin fall in different range sites (Fig. 4).

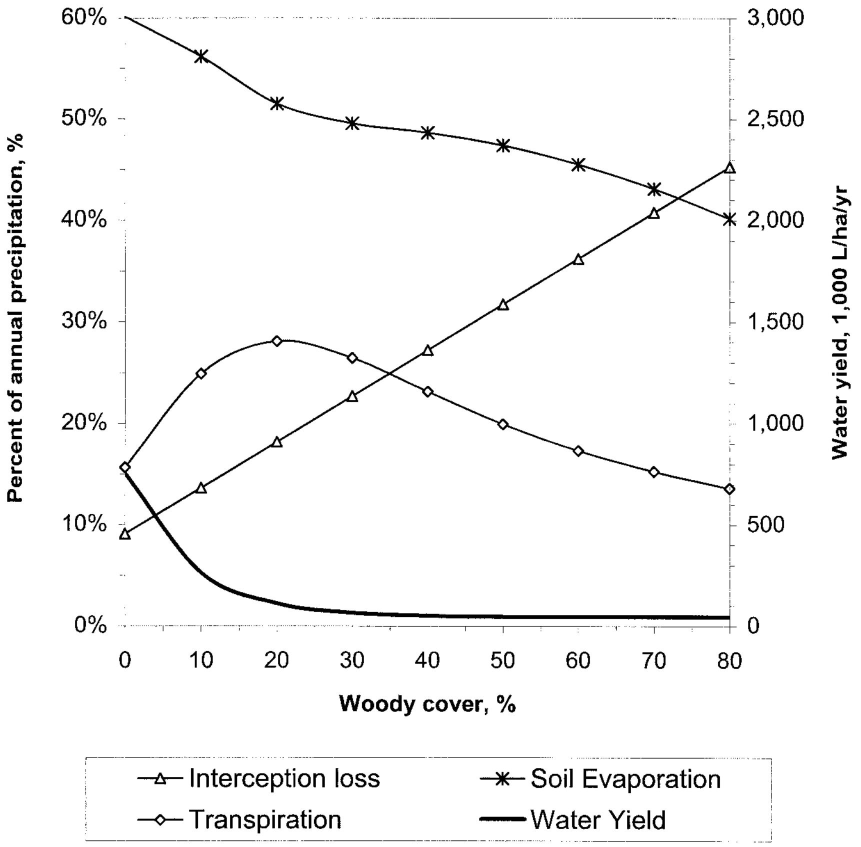

Fig. 5. Water balance for the Cusenbary Draw basin.

Woody Cover and Water Balance

Figure 5 depicts the water balance of the Cusenbary Draw basin as a function of percent woody cover, based on the simulation results with 1990 species composition and associated regression curves. Interception loss increases linearly with increasing woody cover assuming the species composition remains unchanged. The amount of bare ground may increase on Shallow and Low Stony Hill ranges, sites dominated by dense stands of juniper and oak thereby lowing the interception loss of the area not occupied by woody cover. This should have a limited influence on the estimation of interception given the small amount of non-woody cover and the relatively low interception of herbaceous species. For example, an increase in the proportion of bare ground in the non-woody cover from the default 30% to 80% would change the interception from 50.4% to 49.3% on Shallow and Low Stony Hill ranges sites with 80% woody cover. Soil evaporation is greatest at 0% woody cover and decreases as woody cover increases due to the modification of microenvironments by increased shading and reduced wind exposure (Thurow and Hester 1997). The rate of reduction in soil evaporation decreases at woody covers greater than 20%. Transpiration initially increases with increased woody cover. As woody cover increases beyond 20%, however, transpiration begins to decrease in response to the reduced amount of precipitation reaching mineral soil, hence reduced soil water available for transpiration, as a result of increased interception loss. These modeling results indicate that there is a threshold woody cover around 20% over which the reduction of water yield levels off and water yield reaches its lowest level. Below this threshold woody cover, water yield increases exponentially with decreasing woody cover. This implies that brush management effort must reduce the woody cover to less than 20% to have a meaningful contribution to water yield on these rangelands. It also shows that the lower the woody cover the more effective per unit reduction of woody cover for increased water yield.

Effect of Spatial Scale on Assessment of Vegetation Change and Water Yield

Given the differential changes in woody cover on different range sites (Fig. 2) and the different shapes of the woody cover-ET regression curves for different range sites (Fig. 4), it would be misleading to use the average woody cover and the woody cover-ET regression curve for the basin to assess the effect of vegetation change from 1955 to 1990 on water yield. Even assessments based on average woody cover and woody cover-ET regression curve for individual range sites may be inaccurate because of the strongly nonlinear nature of the woody cover-ET regression curves (Fig. 3). An area dominated by an intermediate level of woody cover would have lower water yield than an area with the same average woody cover but dominated by very low and very high woody covers. These considerations illustrate that assessments should be based on frequency distribution of areas with different percent woody cover by range sites. If the woody species composition in 1955 were the same as that in 1990, the changes in woody cover distribution from 1955 to 1990 would have resulted in a

24% increase in water yield. However, water yield from Cusenbary Draw basin actually decreased (over 30%) because of the reciprocal change in juniper and oak cover on the Low Stony Hill and Shallow range sites and the higher interception and transpiration rates of juniper compared to that of oak (Thurow et al. 1987, Owens 1996, Thurow and Hester 1997). Despite improvement in woody cover distribution from the efforts of brush management over the 35 years, the potential increase in water yield, however, was more than offset by the decreased water yield due to compositional changes of woody vegetation caused in part by brush management practices.

Water Yield Ramifications of Brush Management

The hydrologic modeling approach used in this study and the resulting woody cover-ET regression curves can be an effective tool for assessing the implications of brush management scenarios for policy making and educational purposes. In the absence of landowner investment in brush management, the amount of woody cover would increase substantially as was evident on several ranches within the basin that selected not to invest in this form of land management. With no brush management, the Shallow and Low Stony Hill sites were observed to experience over 50% relative increases in woody cover from 1955 to 1990; and the Deep Divide, Bottomland, and Valley range sites were observed to experience relative increases in woody cover as high as 150%. Such increase in woody cover will result in a significant change in water yield. A scenario of no brush management, assuming a 5% increase in woody cover for the shallow sites and a 10% increase in woody cover for the deep sites, would result in a 35% decrease in water yield from the 1990 levels (Table 1). Although this scenario represents one extreme of the spectrum, it may not be far from possible realities in some areas of the Edwards Plateau where large ranches are being subdivided into smaller parcels. These ranchettes are used mainly for recreation and their owners tend to be less interested in brush management (Thurow et al. 2000).

A second scenario examined the possible effect of a hypothetical publicly funded brush management cost-share program designed to increase water yield (Thurow et al. 2000). It required that ranchers clear enrolled land to 3% woody cover and maintain that cover for a 10-year period. The government payment associated with the cost-share was calculated so that the brush management effort would result in zero net financial cost to the rancher. The ranchers who participated in a survey were willing to enroll 40% of their land to be managed at 3% brush cover (Thurow et al. 2000). Assuming 40% of the land in each range site with the least woody cover were enrolled and the woody cover for the rest of the land remain unchanged, this scenario would increase water yield by 43% over 1990 level (Table 1). These results suggest that brush management has the potential to dramatically alter water yield.

Spatial distribution of Brush Management: Water Yield vs. Forage Production

Benefits in water yield and forage production from brush management may differ in different range sites. In this study, the range sites with the highest forage production potential (Bottomland and Valley) (Redeker et al. 1998) had gentler slopes (1 to 5%) and deeper soil resulting in greater soil water storage potential; therefore, these sites had the lowest water yield potential. The range sites with relatively low forage production potential (Low Stony Hill and Shallow) had steeper slopes (3 to 12%) and shallower soil resulting in higher inherent water yield potential (Fig. 4). Reducing the woody cover to 3% on a Low Stony Hill range site would generate 4.8 times more water yield than doing the same on a Bottomland range site. If there is no specific structure in a cost-share program on range site distribution of the enrolled land, it is likely that more low water yield potential (high production potential) land and less high water yield potential (low production potential) land will be enrolled in the program. If the second scenario were modified (a third scenario) to enroll 40% of land in the Cusenbary Draw in range sites with the highest forage production potentials (Bottomland, Valley, and then Shallow), it would increase water yield by 50% over the 1990 level (Table 1). A fourth scenario that enrolls 40% of land in the Cusenbary Draw in range sites with the highest water yield potentials (Low Stony Hill and then Shallow), would increase water yield by 100% over the 1990 level (Table 1). The same amount but different spatial distribution of brush management efforts in these 2 scenarios would result in a 50% difference in water yield.

Population increases are expected to place increasing demands on natural resources, including the surface and subsurface freshwater supplies. These increased demands for freshwater supplies in arid and semi-arid areas are often dependent on rangeland water yield. Incentive programs, such as the publicly funded cost-share program examined by Thurow et al. (2000) have the potential to encourage vegetation management in a way that could increase water yield substantially. Range site-specific woody cover-ET regression curves, developed based on hydrologic model simulations, can be a useful tool for considering the estimated water yield associated with brush management, and a useful component to evaluate trade-offs between benefits in water yield and range production. Such consideration will aid improvement of policy structure. This approach, coupled

Table 1. Woody cover and water balance of the Cusenbary Draw basin for 1990 and 4 scenarios evaluated using woody cover-ET regression curves developed from SPUR-91 hydrologic model simulations (simulated mean precipitation 501 mm/yr).

	1990 cover	No brush management over 35 years[1]	Variations of the revenue neutral brush management program (Thurow et al. 2000) with emphasis on: No preference[2]	Forage production[3]	Water yield[4]
Overall woody cover (% of basin)	23.6%	29.5%	21.7%	17.6%	17.3%
Interception loss (mm/yr)	99.9	148.9	109.5	90.2	87.9
Total ET (mm/yr)	482.7	489.1	474.9	473.6	464.4
Water yield (liter/ha/yr)	182,531	119,070	260,606	274,477	365,541
% difference from 1990 water yield	0%	–35%	43%	50%	100%

[1]5% woody cover increase in Shallow and Low Stony Hill and 10% in Deep Divide, Bottomland, and Valley range sites.
[2]Woody cover is reduced to 3% on 40% of the land in each range site with the lowest woody cover; and remains unchanged on the rest of the land.
[3]Woody cover is reduced to 3% on 40% of the land with highest forage production potentials; and remains unchanged on the rest of the land.
[4]Woody cover is reduced to 3% on 40% of the land with highest water yield potentials; and remains unchanged on the rest of the land.

with remote sensing based woody cover assessment and GIS analysis, can make practical, spatially explicit brush management planning and monitoring at large watershed and regional-scales possible.

There are other concerns associated with increasing water yield through brush management. Spatial patterns of vegetation distribution at the landscape or field scales can have significant effects on the surface hydrologic process and soil erosion (Wu et al. 2000). The carrying capacity and lease value of the land for livestock grazing and/or hunting (Rollins et al. 1988, Thurow et al. 2000) can be enhanced or altered by manipulation of the density and spatial patterns of woody species. Endangered species needs (Keddy-Hector 1992) must also be considered as well as the aesthetic values of the landowner (Rowan et al 1994). Although it is beyond the scope of macro-scale strategic planning process, it is important to stress the needs of meso-scale research and tactical planning practice to address landscape or field-scale patterning of vegetation and their interaction with hydrologic process to minimize soil erosion. Simulation models combined with GIS analysis can provide insight needed to develop spatially explicit and dynamic brush management strategies that can minimize the conflicts and sustain the provision of these multiple values and products of rangelands for generations to come.

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Economics and demographics constrain investment in Utah private grazing lands

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Abstract

In Utah during the early 1990s it was theorized that substantive change was under way in the management of private grazing land. Change was thought to be spearheaded by grazing permittees who feared losing access to public forage and thus wanted to increase carrying capacity of private grazing land as a hedging tactic. We synthesized results from socioeconomic surveys conducted among a target population of 5,067 grazing livestock producers during 1993, 1996, and 1997. This population was evenly divided between permittees and operators wholly dependent on private grazing (e.g., private operators). Our primary objectives were to: (1) test the hypothesis that a sustained upswing in management change was occurring; (2) identify factors associated with operations that "actively" invested in their properties versus those that were "passive"; and (3) identify producer priorities for applied research. Mail and phone surveys were used. Data analysis included descriptive statistics and logistic regression. Compared to private operators, permittees controlled far more private land and livestock and were more profit-oriented and dependent on livestock-derived income. Managers of both groups were aged—37% of the population was >65 years old. Eighty percent of 393 managers surveyed in 1996–7 classified their operations as passive and ranked factors related to aging and economics as main reasons for passivity. Logistic regression and ranking exercises revealed that the active minority was most associated with higher gross annual incomes, more stewardship values, greater willingness to incur debt, and being a permittee. Permittees were more inclined to be active managers because of a greater entrepreneurial orientation compared to private operators, who tended to be hobby ranchers. Our work supported an alternative hypothesis that passivity in land management has been maintained in Utah during the 1990s, largely because incentives were lacking for most of the population to do otherwise. A wealthier minority, however, could still make large investments in their operations because of a superior risk tolerance. We concluded that demographic and economic factors exert the most control over producer behavior today, not access to information or new technology. One consequence is that demand for information and technology can be episodic due to coincident economic, demographic, and policy factors, which also implies that applied research, extension, and policy formulation need to be more opportunistic in response to change. Producers felt that

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Resumen

A inicios de la década de los 90's se teorizó que en Utah estaba ocurriendo un cambio substancial en el manejo de los pastizales privados. Se pensó que el cambio era liderado por los permisionarios de tierras de pastizal quienes temían perder el acceso al forraje público, así buscaron aumentar la capacidad de carga de los pastizales privados como una táctica de bloqueo. Sintetizamos los resultados de muestreos socioeconómicos conducidos durante 1993, 1996 y 1997 entre una población de 5,067 ganaderos. Esta población se dividió uniformemente entre permisionarios y operadores totalmente dependientes de pastizales privados (Por ejemplo, operadores privados). Nuestros objetivos principales fueron: (1) probar la hipótesis de que estaba ocurriendo un mejoramiento ascendente en el manejo. (2) identificar los factores asociados con las operaciones que invirtieron "activamente" en sus propiedades contra aquellas que estuvieron "pasivas" y (3) identificar las prioridades de los productores de investigación aplicada. Se utilizaron encuestas telefónicas y por correo. El análisis de los datos incluyó estadística descriptiva y regresión logística. Comparados con los operarios privados, los permisionarios controlaron mucho mas la tierra privada y el ganado, estaban mas orientados a tener ganancias y dependientes de los ingresos derivados del ganado. Los manejadores de ambos grupos eran personas viejas, 37% de la población tenia mas de 65 años. El 80% de 373 manejadores encuestados en 1996-1997 clasificaron sus operaciones como pasivas y clasificaron los factores relacionados con la edad y económicos como la principal razón de la pasividad. La regresión logística y los ejercicios de clasificación revelaron que la minoría activa estuvo mas asociada con mayores ingresos brutos anuales, mas valores de administración financiera, mayor disponibilidad de contraer deudas y ser permisionario. Los permisionarios se inclinaron mas a ser manejadores activos por su mayor orientación empresarial, comparados con los operarios privados quienes tendieron ser ganaderos por pasatiempo. Nuestro trabajo soporta un hipótesis alternativa que la pasividad en el manejo de la tierra ha sido mantenida en Utah durante la década de los 90's, principalmente por la falta de incentivos para la mayoría de la población para hacer lo contrario. Sin embargo, una minoría adinerada pudo hacer grandes inversiones en sus operaciones debido a su tolerancia superior al riesgo. Concluimos que los factores demográficos y económicos ejercen el mayor control sobre el comportamiento actual de los productores y no el acceso a la información y nueva tecnología.Una consecuencia es que la demanda de información y tecnología puede ser episódica debida a factores económicos, demográficos y políticos, lo cual también implica que la investigación aplicada, extensión y formulación de políticas necesita ser más oportunista en respuesta al cambio. Los productores sintieron que la mejora en el forraje, políticas y lo económico fueron las necesidades de investigación prioritarias. Un pico aparente de retiros entre los propietarios tradicionales de la tierra presagia un cambio rápido y sustantivo en el uso de los pastizales privados de Utah. Casi un tercio de ellos esta planea un retiro y espera vender su propiedad a desarrolladores de terrenos.

forage improvements, policy, and economics were top research priorities. A looming crest of retirements among traditional landowners bodes for substantive and rapid change in the use of Utah private grazing land. Nearly one-third of those planning retirement hope to sell property to land developers.

Key Words: ranching, hobby ranching, land use, technology transfer, sustainable agriculture

The early 1990s were a time of intense rhetoric advocating change in the management of public grazing lands (Workman 1994). This atmosphere increased fears among Utah grazing permittees that they would lose access to public forage. In 1993 it was estimated that 27% of Utah permittees planned to intensify use of private grazing land to compensate for anticipated loss of public grazing (Birkenfeld 1994, Coppock and Birkenfeld 1999). One consequence of this strategy was an apparent increase in producer demand for forage materials, grazing systems, and irrigation technology during the early 1990s (Ralph Whitesides, Utah State University, pers. comm., 1995). Expert opinion from the field also supported the view that a revolution was under way in the use of Utah private grazing lands by 1994 (Karl Kler, NRCS, pers. comm., 1995).

It is important to understand how and why production systems change and the roles played by extension information, technology, policy, and economics. With this overall goal in mind, in 1996 we re-surveyed permittees previously studied in 1993 (Birkenfeld 1994, Coppock and Birkenfeld 1999) and in 1997 we added a similar survey of Utah producers operating only on private land. Our major objectives were to determine: (1) whether substantive change in management of private grazing lands was occurring; (2) major causes and constraints for substantive change; and (3) producer priorities for applied research.

Methods

Target Population and Sampling

Grazing resources in Utah occur on public land (about 80% of the land area) and on a much smaller amount of privately owned land. Private land tends to be located in more mesic environments and thus typically have a higher grazing potential than public lands (Anderson 1989).

The target population for this research consisted of 2 sub-populations of grazing livestock producers: (1) those dependent on public and private grazing lands; and (2) those dependent only on private grazing lands. This target population is very diverse in terms of operation size, reliance on off-ranch income, and motivations for involvement in livestock production (Peterson 1997, Coppock and Birkenfeld 1999, Coppock and Peterson, unpubl. data, 1998).

The permittee sub-population consisted of 2,520 operators and all had access to private grazing land. The process of characterizing this sub-population is provided in Coppock and Birkenfeld (1999). Unlike permittees who were easily identified from public rosters, private-land-only operators (henceforth referred to as private operators) were identified from confidential census lists held by the Utah Agricultural Statistics Service (UASS). The UASS initially identified a potential pool of 6,192 operators relevant to our research. After deleting permittees and other land users extraneous to our objectives we had a sub-population of 2,547. It is possible that the Statistics Service sampling frame excluded private operators who have very few (i.e., <10) grazing livestock because such operators may not always be enumerated as agricultural producers (Delroy Gneiting, UASS, pers. comm., 1997). We thus acknowledge the possibility that omitting these operations could lend bias to our results, but we had no reasonable means to identify them. Overall, our target population for this study consisted of 5,067 operators, evenly divided between permittees and private operators.

The primary results reported in this paper came from telephone surveys of 192 permittees (Peterson 1997) and 201 private operators (Coppock and Peterson, unpubl. data, 1998). The survey of permittees occurred over 16 weeks from June through October 1996. The survey of private operators occurred over 6 weeks during October and November 1997. In all cases, phone calls were preceeded by an introductory letter that explained the purpose of the survey and requested voluntary participation. The survey of permittees was conducted by students at Utah State University (USU), while, for reasons of confidentiality, the survey of private operators was conducted by employees of Utah Agricultural Statistics Services. Differences in the time required to complete the surveying were partially attributable to effects of season—fall was an easier time than summer to locate respondents. The 192 permittees were randomly selected from 340 who had responded to a mailed survey in 1993. This pool of 340 respondents was an unbiased sample of the target population as judged from interviews of non-respondents. Details concerning the mailed survey can be found in Birkenfeld (1994) and Coppock and Birkenfeld (1999). The number of private operators sampled (i.e., 201) was intended to be similar to the number of permittees sampled to satisfy statistical design requirements (Susan Durham, USU, pers. comm., 1996). The overall sampling rate was 7.7% (i.e., 393 out of 5,067). Sample size was estimated to yield 95% confidence intervals having confidence limits within ± 5 percentage points of sample means for binomial response variables (Scheaffer et al. 1979). The major sampling difficulty was getting in touch with respondents listed on the sampling frames. Once people were contacted the rate of survey completion was >95% (Peterson 1997, Delroy Gneiting, UASS, pers. comm.). This indicated that operators were interested in communicating with us.

Hypotheses and Structure of Surveys

In 1993, 32% of permittees were considered "active" managers who were attempting to adapt to anticipated changes in public land access, while 68% were "passive" managers embracing a "wait and see," more risk-averse attitude. About four-fifths of active managers focused on intensified use of private grazing land to increase carrying capacity, while one-fifth focused on economic diversification (Birkenfeld 1994, Coppock and Birkenfeld 1999).

Previously cited anecdotal observations appeared to support the hypothesis that “range reform rhetoric”, in conjunction with relatively high beef prices, was leading to widespread increases in the intensified use of private grazing lands throughout Utah in the early 1990s. Private grazing lands had previously been a relatively ignored production resource (D.L. Coppock, unpubl., 1995). This suggested that fundamental change in production practices could occur primarily as a result of socioeconomic pressure that would restrict the grazing resource base and force producers to invest in smaller acreage and become more efficient. That pressure can be a stimulus for technology adoption and improved production efficiency in agroecosystems was noted by Boserup (1965).

In contrast to predicting a continuous and widespread upswing in intensification, however, an alternative hypothesis was that producer interest in intensification would be episodic or ephemeral. For example, by the mid-1990s a waning of

"Range Reform rhetoric," declines in beef prices (DeeVon Bailey, USU, unpubl. data, 1999), increased costs of inputs, continued aging of the producer population, and attractive investment options off-ranch may have forced a majority of operators to remain conservative and refrain from investing in their grazing operations. Only a minority would make good on plans to invest and intensify resource use. If confirmed, this would imply that producer attitude toward changing their production systems shifts back and forth depending on macro- and micro-level variables such as policy initiatives and economic incentives.

The test of these alternative predictions, and explaining why operators selected an active versus passive strategy, constituted the main thrust of this study. All survey respondents were lumped into active or passive categories and it was noted whether operators maintained fidelity to, or altered, strategy during the dynamic period of 1992–3 to 1996–7. Active operators were defined as all who were engaged in "substantive" forms of intensification, diversification, or extensification with their private-land operations (Peterson 1997). Intensification typically involved efforts to increase carrying capacity via forage improvements and irrigation systems. Diversification implied increasing the variety of income flows by investing in new on-ranch enterprises such as recreation concessions and/or exotic livestock. Extensification involved expanding the private land base for grazing. This primarily is done through land purchase, but leases and other forms of resource exchange also are used. Given the wide range of wealth in our target population, the definition of "substantive" was relative to the resources of each respondent. Substantive commitments involved dedication of monetary or other resource investments that were large and meaningful in the opinion of respondents. Passive operators were defined as all who were not active (Peterson 1997). This included operators who showed some form of inertia or resistance to investing in their operations. Sources of inertia or resistance included: (1) change being viewed as unnecessary; (2) change being viewed as too expensive or risky; (3) pending retirement; (4) desire to get out of ranching and to sell property and other assets; (5) operators planning to diversify off-ranch; and (6) desire to increase profit margins from livestock production by reducing inputs. Passive behavior has its own logical rationale. We therefore did not interpret passive behavior in a negative sense compared to active behavior.

We hypothesized that compared to operations that were passively managed, those that were actively managed would tend to have larger scales of production and managers would tend to have higher incomes and more formal education (Rogers 1983, Coppock and Birkenfeld 1999). Larger operations were expected to be more dependent on income from livestock production and have more of a business orientation compared to smaller operations that are often dominated by hobby values and managers with substantial sources of off-ranch income (Coppock and Birkenfeld 1999). Finally, we expected overall that the sub-population of permittees would have a greater proportion of active managers compared to the sub-population of private operators. This was largely because the permittees should be more concerned about making private-land investments in anticipation of changes in public grazing policies (Peterson 1997). In this regard the sub-population of private operators served as a "control" group.

The phone survey for permittees consisted of 2 distinct sections. The first section had 20 questions that sought: (1) information on AUMs obtained from public land, including details on any recent cuts in AUMs; (2) confirmation of coping tactics in 1993 and 1996; (3) up to 3 ranked reasons to explain why the 1996 coping tactic was selected; (4) up to 3 ranked reasons to explain any change in coping tactics between 1993–6; (5) self-rankings [scaled from 1 (lowest) to 5 (highest)] to reveal the operator's level of confidence in the future, level of commitment to keeping operations going, level of willingness and ability to assume more debt to invest in their production systems, and suitability of their land holdings for technical improvement; (6) ranked opinions on roles of prices, weather, and politics on planning and management of operations; and (7) up to 3 ranked priority problems viewed as most critical for applied research. The second section of the survey had 10 options on color-coded sheets to make interviewing easier. One option would be filled out depending on coping tactic for 1996. For example, if an active tactic to intensify use of private grazing land was selected in the first section, the interview would proceed with 23 questions under option 6 in the second section that dealt with details of intensification plans. If a respondent noted a passive tactic to retire and sell off property in the first section, the interview would proceed with 4 questions under option 2 in the second section that dealt with these details. Phone surveys varied in duration from 15 min to 1 hour with an average of 40 min. Active tactics required more time to document than passive tactics. When questions required open-ended responses, in no instance were respondents coached or prompted by enumerators. A copy of the survey is in Peterson (1997). Again, detailed background information on 340 permittee operations had been previously collected with a mail survey by Birkenfeld (1994). To reduce the chance that phone survey would become too tedious, background information was not re-collected in 1996.

The 1997 phone survey for private operators was very similar to that used for permittees except for the following: (1) background information on production resources of operations and the goals, concerns, felt needs, gross annual income, age, and formal education of operators was collected in the first section of the private-operator survey since these data had not been previously collected; (2) background information on management strategy 5 years earlier in 1992 was collected based on recall of respondents; (3) no information was sought on use of public land, since that was irrelevant; and (4) compared to the phone survey of permittees, the second section of the private operators survey was altered to make it more concise and manageable for enumerators. Design of the second version of the survey benefited from our experiences with the first version. As a result of adding questions to the first section and making the second section more concise, the overall time required to complete phone surveys for private operators was nearly identical to that for the permittee survey (Delroy Gneiting, UASS, pers. comm., 1998).

Data Analysis

Sub-populations of permittees and private operators were described and contrasted in terms of the personal attributes of managers and production strategies and resources of operations. Means were compared between sub-populations using 95% confidence intervals (95% CI).

Four-celled contingency tables were used to depict fidelity of operators to active and passive categories of coping strategies between 1992/3 and 1996/7. The Chi Square test was used to compare year x strategy distributions between permittees and private operators.

As previously noted, several survey questions involved ranking exercises. These prominently included having operators rank: (1) 3 factors that most influenced their choice of coping strategy; and (2) 3 priorities for applied research most relevant to their production problems. We opted for a descriptive approach for analyzing ranking data because of a high number of empty data cells; i.e., many respondents volunteered top-ranked responses but often failed to give second- and/or third-ranked responses. We analyzed these data by scoring top-ranked responses as worth 3 points, second-ranked responses as worth 2 points, third-ranked responses as worth 1 point, and then adding ranking points for each factor or priority across all respondents. The relative importance of each factor or priority was merely based on the total ranking points as a proportion of the grand total.

We used a logistic regression package (SPSS 1992) to reveal factors statistically associated with active operations in 1996–7. Logistic regression was used because it can combine continuous and discrete information in the same analysis (Hosmer and Lemeshow 1989). We had 1 discrete response variable (i.e., active versus passive) and 9 possible explanatory factors that were discrete or continuous.

The 9 factors were first examined for problems of multi-colinearity, but this was not evident ($P > 0.05$). All 35 pairs of discrete factors had Spearman's correlation coefficients <0.34, while the 1 pair of continuous factors had a Pearson's correlation coefficient <0.03. Bohrnstedt and Knoke (1994) recommend deletion of factors due to risk of multi-colinearity only when correlation coefficients exceed 0.80. We therefore proceeded with the 9-factor analysis.

The logistic model was sequentially built from the 9 factors based on previously introduced theory. Factors were added in order of their presumed importance (i.e., higher to lower) in explaining active management behavior. Ordering is important because sequential interaction among factors can influence P values in the final model. The ordering was: (1) INCOME; (2) DEBTABLE; (3) DEBTWILL; (4) PERINC; (5) PUBLIC; (6) LANDSUIT; (7) EDUCATE; (8) AGE; and (9) SOCIORGS. The first 4 reflected economic issues thought pre-eminent in promoting investment, while the fifth and sixth reflected resource tenure and quality. The last 3 reflected important personal characteristics of operators (Rogers 1983), but we anticipated less variability in these features among the producer population. Despite the emphasis on ordering, it is fair to say that the logistic analysis had an exploratory character given the dearth of similar work in rangeland systems (Coppock and Birkenfeld 1999).

The ranking method and logistic regression offered complementary approaches to address the important question of why active or passive coping strategies are pursued. The logistic regression offered a more objective analysis, but it's utility could be limited if critical explanatory factors happened to be omitted or misrepresented in the data. Conversely, while ranking exercises were limited by subjectivity of respondents, the spontaneity afforded by open-ended questioning could reveal new insights.

Results

Attributes of Sub-Populations

We obtained data from permittees and private operators living in all 29 Utah counties (Birkenfeld 1994, Peterson 1997, Coppock and Peterson, unpubl. data). Personal attributes for permittees and private operators are shown in Table 1. In general, permittees and private operators tended to be similar in terms of average age, level of formal education (i.e., typically high school graduates), duration of managerial experience, and degree of community involvement. Personal commitment to operations was relatively strong for both groups despite a weaker confidence in the economic future. The age distribution of operators is illustrated in Figure 1 and this shows a lack of recruitment in younger age classes. Out of a random sample of 393 operators, only 3% were under age 35 while 37% were between the ages of 66 and 90.

More distinctions between permittees and private operators were evident from comparisons of production motivations

Table 1. Descriptive attributes ($\bar{x}$ ± 95% CI) of the operator and management strategy for 2 categories of Utah grazing livestock producers, 1992–7.

Attributes	Permittees[1]	Private Operators[2]	P
Operator			
Age (yr)	56 ± 1.8	59 ± 1.8	NS
Time managing operation (yr)	28 ± 2.4	23 ± 2.0	*
Formal education[3]	2.7 ± 0.2	3.1 ± 0.2	NS
Social memberships[4]	2.0 ± 0.8	2.1 ± 0.2	NS
Confidence in future[5]	3.6 ± 0.2	3.2 ± 0.2	NS
Commitment to operation[6]	4.3 ± 0.2	3.8 ± 0.2	NS
Management Strategy			
Profit oriented (%)[7]	45 ± 6	31 ± 6	*
Hobby oriented (%)[7]	22 ± 4	41 ± 6	*
Profit and hobby oriented (%)[7]	27 ± 4	24 ± 6	NS
Passive managers (%)[8]	70 ± 4	90 ± 4	*
Plan to retire (%)	28 ± 4	51 ± 6	*
Other inertia (%)[9]	39 ± 6	37 ± 6	NS
Focus off-ranch (%)[10]	3 ± 2	2 ± 2	NS
Active managers (%)[8]	30 ± 4	10 ± 4	*
Intensifiers (%)[11]	16 ± 4	4 ± 2	*
Diversifiers (%)[12]	4 ± 2	2 ± 2	NS
Extensifiers (%)[13]	10 ± 2	4 ± 2	*

*Significant at the 0.05 level.
[1]Sample sizes ranged from 192 to 340 respondents.
[2]Sample size was 201 respondents.
[3]Level of formal education was scaled as 1 (<12 years of schooling); 2 (high school graduate); 3 (vocational training after high school); and 4 (attended college).
[4]Level of social memberships was scaled as: 1 (0); 2 (1 to 3); 3 (4 to 6); and 4 (>6).
[5]Confidence was scaled as: 1 (very unconfident); 2 (somewhat unconfident); 3 (neutral); 4 (somewhat confident); and 5 (very confident).
[6]Commitment was scaled as: 1 (very uncommitted); 2 (somewhat uncommitted); 3 (neutral); 4 (somewhat committed); and 5 (very committed).
[7]Respondents selected 1 answer that best described their goal of managing livestock. "Hobby" implies that livestock were raised more for lifestyle reasons and ancillary income generation compared to a profit-minded, business orientation.
[8]Passive managers were those who anticipated selling or transferring property, lacked resources to implement change, saw no need to change management from traditional practices, were cutting back on production inputs, etc. Active managers were those who were engaged in intensifying, diversifying, or extensifying (i.e., expanding) their grazing operations.
[9]"Other inertia" largely consisted of those who lacked resources to change, saw no need to change, or were cutting back on inputs.
[10]Typically an off-ranch focus involved diversifying into more off-ranch employment.
[11]Intensifiers were investing in property or animals to increase per unit productivity.
[12]Diversifiers were creating new income-earning opportunities on-ranch.
[13]Extensifiers were expanding by buying or leasing more land.
Sources: Birkenfeld (1994), Peterson (1997), and Coppock and Peterson (unpubl., 1998).

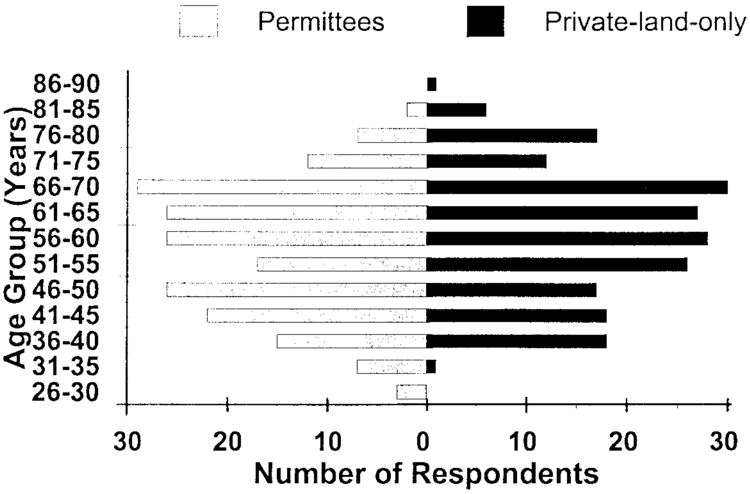

Fig. 1. Age distribution for land managers who were public grazing permittees (n=192) or operators with a sole dependence on private grazing resources (e.g., private operators; n = 201) in Utah during 1996–7.

and management strategies (Table 1). Permittees were significantly more profit-oriented than private operators, while the latter were twice as likely to be hobby-oriented. Managerial passivity was very high for both groups in 1996–7. The major difference was in terms of pending retirements—almost twice as many private operators had plans for imminent retirement compared to that for permittees. Permittees were 3 times more likely than private operators to be active managers, a difference largely attributable to a higher occurrence of permittees who were intensifiers and extensifiers (Table 1).

Differences were also evident between the 2 groups when considering primary sources of income and operation scale (Table 2). On a relative basis, permittees reportedly received nearly 3 times as much livestock-derived income than private operators; consequently, permittees had a lower relative dependence on off-ranch income. On average, permittees had much larger operations than did private operators. Permittees averaged 15 times more private grazing land, 3.6 times more irrigable grazing land, 3 times more cropland, 5.6 times more beef cattle, and over 16 times more sheep.

Cuts in AUMs on public grazing land were reported by permittees for 1993–6. Forty-two operators (or 22% of the 192) had experienced cuts in AUMs. These cuts were usually relatively minor and temporary, however, due to local drought or loss of forage from wildfire. These cuts were not interpreted to be due to any major shift in public grazing policies.

Temporal Patterns of and Reasons for Coping Strategies

Temporal patterns in coping strategy are shown as contingency tables in Figure 2 (a-c). The pattern for permittees differed from that of private operators ($P < 0.05$, df = 3, $X^2 = 10.3$); this was largely attributable to a higher number of private operators being consistently passive compared to permittees. When both groups were combined, 76% of respondents were consistently passive, 9% were consistently active, and 15% varied their strategies.

Reasons given by respondents for selecting coping strategies are shown in Table 3. These are largely self-explanatory. It was somewhat surprising, however, to see "advancing age/declining health" so commonly mentioned as a justification for passive coping strategies. Passivity was also often justified on the basis of economic constraints such as low beef prices and low returns on investment in grazing operations.

Our logistic regression model was significant overall at $P < 0.001$. Out of 9 factors, however, only 4 were statistically significant ($P < 0.05$). Our results indicated that micro-economic factors, community stewardship, and public-land dependence were significantly associated with active coping strategies (Table 4). The 5 factors not included in the final model were PERINC ($P = 0.49$), EDUCATE ($P = 0.31$), DEBTABLE ($P = 0.30$), AGE ($P = 0.18$), and LANDSUIT ($P = 0.13$).

Priorities for Applied Research

Producer priorities for applied research are displayed in Table 5. Variation between permittees and private operators was minimal so results were combined. These results are largely self-explanatory, but somewhat paradoxical in light of findings on coping strategies. For example, despite that only a small minority (i.e., 10 ± 1%) of all operators were "intensifiers" seeking to increase carrying capacity on private grazing land, the dominant research priority expressed by both permittees and private operators was work devoted to pasture or forage improvements.

Discussion

Permittees vs. Private Operators

Perhaps the most important similarity among permittees and private operators was their demographic profiles. That 37% of all operators were age 66 or older is an important finding and confirms statistics for Utah farmers and ranchers previously reported by Godfrey (1992). The phenomenon of low recruitment among agricultural producers is not unique to Utah—the mean age of agricultural producers has

a) Permittees (n=192)

1996 \ 1993	A	P
A	28	13
P	21	130

b) Private Operators (n=201)

1997 \ 1992	A	P
A	6	13
P	14	168

c) All combined (n=393)

1996-7 \ 1992-3	A	P
A	34	26
P	35	298

Fig. 2 (a-c). Temporal patterns for active (A) and passive (P) management behavior for public grazing permittees and operators soley dependent on private grazing resources, 1992–7, in Utah.

Table 2. Descriptive attributes ($\bar{x}$ ± 95% CI) of the land, labor, and capital for 2 categories of Utah grazing livestock producers, 1992–7.

Attributes	Permittees[1]	Private Operators[2]	P
Labor and Financial			
Annual labor from household (%)[3]	85 ± 2.6	93 ± 2.8	*
Gross annual income			
Total[4]	2.4 ± 0.2	2.6 ± 0.2	NS
From livestock (%)[5]	49 ± 3.6	17 ± 3.0	*
From crops (%)[5]	6 ± 1.4	6 ± 1.8	NS
From wildlife (%)[5]	<1	<1	NS
From off-ranch (%)[5]	45 ± 3.8	76 ± 4.0	*
Credit access[6]	2.1 ± 0.2	2.1 ± 0.2	NS
Willingness to assume debt[7]	2.5 ± 0.2	2.2 ± 0.2	NS
Ability to assume debt[7]	3.3 ± 0.2	3.5 ± 0.2	NS
Land and Livestock			
Deeded grazing land[8]			
Total (ac)	2,428 ± 544.0	166 ± 88.0	*
Irrigable (ac)	177 ± 43.2	49 ± 19.6	*
Deeded cropland (ac)	164 ± 41.6	60 ± 19.0	*
Grazing land suitability[9]	3.5 ± 0.2	3.9 ± 0.2	NS
Beef cows (hd)	141 ± 13.8	25 ± 4.5	*
Other beef cattle (hd)[10]	95 ± 52.2	17 ± 4.1	NS
Sheep (hd)[11]	212 ± 56.6	13 ± 5.2	*
Public grazing AUMs (%)[12]	39 ± 1.4	NA	

*Significant at the 0.05 level.
[1]Sample sizes ranged from 192 to 340 respondents.
[2]Sample size was 201 respondents.
[3]Percent annual labor requirements for the operation as met by household (i.e., family) members was estimated by respondents.
[4]Total gross annual income was scaled as: 1 (≤ $25,000); 2 ($25,001 to $40,000); 3 ($40,001 to $60,000); 4 ($60,001 to $100,000); and 5 (>$100,000).
[5]Percent gross annual income derived from livestock, crops, wildlife, or off-ranch sources was estimated by respondents.
[6]Credit access was scored as: 1 (an open line); 2 (credit is accessible if the investment is justified to the lender); 3 (operator is typically unqualified to receive credit); 4 (credit has never been sought to improve the operation).
[7]Debt characteristics were scaled as: 1 (very unwilling/unable); 2 (somewhat unwilling/unable) 3 (neutral); 4 (somewhat willing/able); and 5 (very willing/able).
[8]Tabulated figures focus on owned property because it was thought that owned property is more liable to be better managed or improved. Land leasing is common, however, especially among private-land-only operators. The typical length of leases was 1 year.
[9]Suitability of owned grazing land for technical improvements in general as judged by the respondent. Suitability was scaled as: 1 (very unsuitable); 2 (somewhat unsuitable); 3 (neutral); 4 (somewhat suitable); and 5 (very suitable).
[10]Other beef cattle included stockers and yearlings being fattened.
[11]Mean holdings of sheep for permittees is misleading. A few permittees manage thousands of sheep while the majority have none. Sixty-seven permittees out of 340 surveyed managed sheep.
[12]The percent of AUMs on public grazing was calculated by Birkenfeld (1994).
Sources: Birkenfeld (1994); Peterson (1997), and Coppock and Peterson (unpubl., 1998).

ducers. This was illustrated by the smaller size of their operations, income strongly skewed toward off-ranch sources, and their predominant objective for livestock husbandry was more related to hobby incentives (i.e., lifestyle factors and generation of ancillary income). Although permittees are very diverse in socioeconomic terms [i.e., nearly 50% of permittees are also hobbyists (Coppock and Birkenfeld 1999)], on average permittees were more profit-driven and dependent on livestock-related income compared to private operators. Although permittees and private operators were very similar in terms of overall number of operations, permittees controlled about 93% of private grazing land, 85% of the beef cattle, and 94% of the sheep. When isolating resource control based on production motivation, regardless of public-land dependence, it is notable that operations run by persons with hobby incentives controlled about 20% of private grazing land and 20% of grazing livestock. Producers whose motivations were dominated by hobby incentives added to 32% of the target population—if producers with any hobby incentive are added this subgroup increases to 62% of the target population. The findings that hobbyists make up a large proportion of the producer population and control significant amounts of animal and land resources are important because other work indicates, compared to purely profit-driven producers, that hobbyists are less inclined to adopt recommended range and livestock management practices (Coppock and Birkenfeld 1999).

been rising in western states over the past 30 years (Donald Snyder and Richard Wilde, USU, unpubl. data, 1992; Donald Snyder, USU, pers. comm., 1999). Low recruitment is attributable to changing career incentives and declining profitability and increasing risk for family-based operations. Continuity is also limited by high initial investment costs for contemporary operations. Down-payments ranging from one-third to one-half of total property value are common and often pose insurmountable barriers to younger people hoping to enter agricultural professions (Donald Snyder, USU, pers. comm., 1999).

There were marked differences between permittees and private operators in terms of resource control and motivation for involvement in grazing livestock production. Private operators, in general, are best described as truly part-time livestock pro-

Table 3. Priority reasons given by 393 randomly selected grazing livestock producers in Utah regarding why they have chosen active versus passive management strategies, 1996–7[1].

Priority Reason	Ranking Points	Percent
For Being an "Active" Manager		
Increase profitability, productivity	116	42
Maintain lifestyle, value good management	72	26
Expect loss of access to public land grazing	45	16
Other (7 reasons combined)	43	16
Total	276	100
For Being a "Passive" Manager		
Retirement[2], aging, poor health	546	43
Economic constraints[3]	443	35
Change not needed	147	12
Land constraints[4]	81	6
Other (3 reasons combined)	46	4
Total	1,263	100

[1]Based on rankings where respondents volunteered up to 3 priority reasons each. The top priority received 3 ranking points, the second received 2, and the third received 1. This system should have yielded 2,358 total ranking points (i.e., 6 x 393). On average, however, respondents only gave 1 or 2 reasons.
[2]Specifically, "estate planning" was often mentioned as a primary retirement concern that led to passive management behavior.
[3]Low beef prices, low rate of return on investment in beef grazing operations, etc.
[4]Low availability of private grazing land; urban/rural conflicts, etc.
Sources: Peterson (1997), Coppock and Peterson (unpubl., 1998)

Table 4. Logistic regression results for factors associated with active management behavior among 393 randomly selected grazing livestock producers in Utah, 1996–7[1].

Factor	Beta Coefficient[2]	Odds Ratios[3]
Total Gross Annual Income (INCOME)[4]	0.40	1.49**
Ability to Assume Debt (DEBTABLE)[5]	0.14	1.15
Willingness to Assume Debt (DEBTWILL)[5]	0.30	1.35**
Percent Income from Off-Ranch (PERINC)[6]	0.01	1.00
Public Land Dependence (PUBLIC)[7]	1.33	3.80***
Land Suitability (LANDSUIT)[5]	0.21	1.23
Formal Education (EDUCATE)[8]	0.22	1.24
Age (AGE)[9]	-0.02	0.98
Social Memberships (SOCIORGS)[10]	0.72	2.04**

,*Significant at the 0.01 and 0.001 levels, respectively.

[1]Nine social, economic, and resource factors were used in this analysis. After identifying the 4 significant factors above, the analysis was re-run to include interactions among significant factors. No interactions were significant, however.

[2]The beta coefficients are used in the regression model as follows:

$$\pi(x) = \frac{\exp[g(x)]}{1 + \exp[g(x)]}$$

where (x) is the "likelihood of being active" and g(x) = -7.09 + 0.40(INCOME) + 0.14(DEBTABLE) + 0.30(DEBTWILL) + 0.01(PERINC) + 1.33(PUBLIC) + 0.21(LANDSUIT) + 0.22(EDUCATE) – 0.02(AGE) + 0.72(SOCIORGS)

[3]The odds ratios give the increase in the likelihood that an operator will be an active manager with each level unit of increase in a given factor. For example, as "willingness to assume debt" increased 1 level from among "very unwilling", "somewhat unwilling", "neutral", "somewhat willing", and "very willing", the odds an operator would be active increased by 35%.

[4]Income levels were scaled as: 1 (≤$25,000); 2 ($25,001 to $40,000); 3 ($40,001 to $60,000); 4 ($60,001 to $100,000); and 5 (>$100,000).

[5]Debt and land suitability factors were variously scaled as: 1 (very unwilling/unable/unsuitable); 2 (somewhat unwilling/unable/unsuitable); 3 (neutral); 4 (somewhat willing/able/suitable); and 5 (very willing/able/suitable).

[6]Percent gross annual income earned from off-ranch sources was estimated by respondents.

[7]Public land dependence was scaled as: 1 (private operators: zero dependence) or 2 (permittee: some dependence). A permittee was about 3-times more likely to be an active manager compared to a private operator, but in absolute terms active managers were in a minority (i.e., 10% versus 30% for private operators and permittees, respectively).

[9]Age in years as provided by respondents

[10]Level of social memberships were scaled as: 1 (0); 2 (1 to 3); 3 (4 to 6); and 4 (>6).

Source: Ralls, Peterson, and Coppock (unpubl., 1998).

Sleight, USU, pers. comm., 1999). Incentives to help farm and ranch families keep properties intact and under agricultural use across generations are often undermined by desires of retirees and their heirs to cash-out. Even if an heir wants to keep an operation going, a sale is typically forced by other family members (Weldon Sleight, USU, pers. comm., 1999).

Change in land use offers new challenges for range research and resource management. If it is assumed, for example, that land development implies creation of residential areas dominated by "ranchettes," emerging problems of resource fragmentation and dominance of hobby-motivated livestock producers could prevail in these areas. We speculate that the remainder of private grazing lands kept in more traditional forms of land use would ultimately be managed by fewer, wealthier individuals as economic shake-outs claim more victims. Such a trend could be favorable for some aspects of natural resource management, however, as wealthier individuals managing larger operations appear more able to implement innovative resource management plans compared to those with lower incomes and smaller operations (Harris et al. 1995, Coppock and Birkenfeld 1999).

Overall, the percentage of operations carrying out intensification tactics was 10%, suggesting that approximately 500 operations were involved in absolute terms. Of this 500 about 100 had a focus on intensifying beef production through changes in animal-based feeding or breeding management (Peterson, unpubl. data, 1997; Coppock and Peterson, unpubl. data, 1998). Land-based intensification projects reported to us included: (1) converting irrigated alfalfa to irrigated pasture; (2) replacing shrubby upland vegeta-

Active vs. Passive Management

Compared to being a private operator, being a permittee did have a positive effect on incidence of active management behavior. While this empirical result confirmed one of our hypotheses, the primary cause of active behavior did not appear to be what we expected, namely fear of permittees that they would lose access to public grazing. Rather, the dominant factor seems to be the heightened entrepreneurial orientation of permittees in general compared to private operators. This was interpreted from the ranked responses of operators in conjunction with other data (Peterson 1997) indicating permittees overwhelmingly make planning and management decisions based on economic—not political—criteria.

Averaged across permittees and private operators, those who classified themselves as passive managers by 1996–7 comprised a surprising 80% of the population. Overall, pending retirement was a major component of passivity. This looming crest in turnover of land managers has important implications for land use. For example, 43% of permittees planning to retire wanted to sell their properties to land developers, while 57% wanted to keep operations in the family (Peterson 1997). For private operators about 25% of those planning to retire wanted to sell their properties to land developers, while 67% wanted to keep operations in the family (Coppock and Peterson, unpubl. data, 1998). Averaged for the target population overall, 39% of operators have imminent plans to retire. One-third plan to sell property to land developers.

Stemming a tide in rural land development is difficult in Utah as elsewhere in the western United States (Weldon

Table 5. Priorities for applied research given by 393 randomly selected grazing livestock producers in Utah, 1996–7[1].

Research Priority	Ranking Points	Percent
Pasture improvements[2]	432	40
Policy analysis[3]	206	19
Marketing, financial management	107	10
Technology transfer	75	7
Resource management systems	70	6
Weed/pest control	55	5
Livestock health	48	4
Other miscellaneous issues[4]	92	9
Total	1,085	100

[1]Based on rankings where respondents volunteered up to 3 priorities each. The top priority received 3 ranking points, the second received 2, and the third received 1. This system should have yielded 2,358 total ranking points (i.e., 6 x 393). On average, however, respondents only gave 1 priority.

[2]"Pasture" should be broadly interpreted to mean forage improvements relevant to both irrigated and rain-fed conditions.

[3]Land use, urban/rural conflicts, environmental regulations, trade policy, etc.

[4]Included a number of poorly defined "agricultural" and "personal" issues as well as public education themes.

Sources: Peterson (1997) and Coppock and Peterson (unpubl., 1998).

tion with improved grasses after plowing, burning, and/or chemical treatment; (3) expanding forage grasses under irrigation; (4) improving irrigation and fencing systems; (5) introducing new forages to wet meadows; (6) leveling land and improving irrigation on wet meadows; and (7) improving and expanding native grass and alfalfa hayfields (Peterson 1997, Coppock and Peterson, unpubl. data, 1998).

Results from logistic regression and ranking exercises revealed operators able to carry out intensification plans were those with a combination of higher gross annual incomes, stewardship values, and a greater willingness to assume debt in support of production improvements. We interpret willingness to assume debt as indicative of a higher risk tolerance characteristic of wealthier operators. Wealthier operators can afford to be less concerned about marginal returns from investment in grazing operations [on the order of 2% (Capps and Workman 1982)] and some may even be able to indulge in a few land-management "whims" that may not be justified purely on an economic basis. As another testimony to the role of wealth in promoting investment in private grazing lands, most of our "intensifiers" were not looking for means to co-finance or subsidize their projects. This was despite costs estimated between $5,000 and $250,000 per project by respondents (Peterson 1997). Our work confirmed the view of Rogers (1983) that wealth is a reliable predictor of innovative, risk-tolerant behavior.

Attempts to diversify operations were relatively rare and comprised only 3% of all operations surveyed. Expert opinion endorses enterprise diversification as a major risk management strategy under economic stress (Larry Butler, NRCS, pers. comm., 1997). Our findings confirm earlier work (Coppock and Birkenfeld 1999) that only a very small number of private operators and permittees in Utah are considering economic diversification.

Attempts to expand operations were also rare and comprised only 7% of all operations surveyed. Managers who focused on expansion of operations were among the wealthiest of all survey respondents (Peterson 1997).

Dynamics of Coping Strategies

Our results lead us to reject the hypothesis that active management behavior was on a sustained upswing during the 1990s. Our observations instead supported the alternative hypothesis that managerial passivity was maintained—or even increased—across the population overall.

Why should passivity be maintained? We suspect that a combination of macro- and micro-level factors explain observed patterns. First, it was evident that implementation of policy reforms on most public grazing lands in Utah had not occurred by 1996, as evidenced by the lack of permanent cuts in AUMs for permittees in our sample. In addition, intense public debate on "Range Reform" appeared to wane by the mid-1990s (D.L. Coppock, pers. obs., 1998). These trends probably compelled many permittees to shelve plans they had for intensification, especially if other socioeconomic factors on the horizon appeared unfavorable.

We speculate that widespread adoption of novel technology and management systems for private grazing lands could have occurred if beef prices remained high, pressure to reduce access to public grazing had increased, and the average producer was further from retirement age. With a sustained drop in real beef prices since 1995, however, it is unlikely that producers would have been able to secure the financing for substantive production improvements (DeeVon Bailey, USU, pers. comm., 1999). Widespread enthusiasm for interventions such as irrigated pasture improvements in the early 1990s was probably a result of an initial overreaction by producers to Range Reform rhetoric (D.L. Coppock, pers. obs., 1998) in combination with optimism engendered by high profits enjoyed by beef operations during 1988-94 (DeeVon Bailey, USU, unpubl. data, 1999).

Perhaps our most important observation was that operators perceived the combination of their advancing age and declining health as the greatest impediment to active management behavior. "Declining health" was discovered from the open-ended ranking questions—age per se was not significant ($P = 0.18$) in the logistic regression. Despite awareness that the average age of agricultural producers is increasing in the western US (above), the obvious consequences that aging has for resource management and technology transfer are not apparent from the literature. It certainly makes sense that as producers near retirement they put more resources into estate planning to the detriment of investing in their production systems.

For new technology or information to have maximum utility, demographic and economic factors need to be in a favorable alignment. For example, a younger population of wealthier operators responding to growing markets for livestock products would represent such an alignment. Factors could be integrated into a state-and-transition model for human management behavior much like that proposed for describing vegetation dynamics on arid rangelands (Westoby et al. 1989). Similarly, rates of adoption of relatively expensive technology and management systems could be expected to follow more of an episodic or ephemeral pattern coincident with favorable and sustained alignment of economic and demographic variables. This concept is unlike the traditional sigmoid curve model proposed for many forms of technology diffusion where technology adoption is a cumulative and continuous process (Rogers 1983).

Considering our findings overall, the patterns we observed support contentions that local innovation in contemporary agricultural systems is constrained more by macro- or micro-level economic and demographic phenomena rather than lack of technology or information (Boserup 1965, Holechek et al. 1994, Udo and Cornelissen 1998). Conversely, when economic and demographic factors are favorable, key technology or information can be more rapidly taken up and change can result. Understanding the difference between the 2 scenarios is important. It is illuminating to note that managerial passivity was never justified by our respondents because of a lack of extension information or production technology. In this case, producer inertia would not be overcome with more extension information.

Finally, survey respondents indicated that technical (i.e., forage-related) and social (i.e., policy, economics) research were both relevant to their priority problems. Given the low percentage of intensifiers in our target population, we were somewhat surprised that forage research would still be regarded as the highest research priority. This finding confirmed previously cited anecdotal observations that producer interest in irrigated pasture and related topics is real. We reconcile these views by speculating that producers see ongoing forage research as useful to mitigate future risks. For example, should the time come when a majority of operators are suddenly forced to invest in private grazing lands, they want relevant technology to be available.

Conclusions

Macro- and micro-level economics and producer demographics are the major constraints for increased investment in Utah private grazing lands at the present. The joint occurrence of favorable economic and demographic factors, in conjunction with resource pressure, drives change in land management and demand for technology and information in an episodic fashion. Operations most likely to be in a continuous process of active management, investment, and innovation are the minority having more financial resources, stewardship ethics, and tolerance of risk. A looming crest in retirement among permittees and private operators is currently having a negative effect on investment in Utah private grazing lands.

Applied research and extension should prepare now to meet new challenges afforded by pending changes in land use and land users. Applied research and extension need to act with a degree of opportunism to improve response to rapid change. If it is assumed that helping sustain traditional forms of land use is desirable in some cases, more attention to innovation in policy formulation and public education is needed to achieve this end. Broad-based efforts that collectively encourage younger people to stay on the land would address a cornerstone of the problem.

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Range research: The second generation

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Abstract

The decade of the 1920s was somewhat of a paradox for range science. A. W. Sampson published 3 books that were widely used as text for higher education classes in range management. The United States Department of Agriculture, Forest Service expanded their mandate to manage grazing on National Forest and began to apply the principles of plant ecology and physiology that were being enumerated by range scientists. At the same time millions of acres of public domain outside the National Forest remained as free range and continued to decline in productivity. Progress was made in applying animal behavior technology to improve the uniformity of range forage utilization. This was especially apparent in regard to sheep and goats which were herded on rangelands. The management tools utilized were herding techniques, salt distribution and water developments. Restoration of range productivity and the place of wildfires in range ecosystems remained very controversial subjects.

Key Words: herding technology, range text, wildfires, salting, wildfires.

Resumen

La década de 1920 fue algo como una paradoja para la ciencia de manejo de pastizales. A.W. Sampson publico 3 libros que fueron ampliamente utilizados como texto en clases universitarias de manejo de pastizales. El Servicio Forestal del Departamento de Agricultura de los Estados Unidos, amplio su mandato para manejar el apacentamiento en los bosques nacionales y comenzo a aplicar los principios de ecología y fisiología vegetal que estaban siendo enumerados por los científicos en manejo de pastizales. Al mismo tiempo millones de acres de dominio publico fuera de los bosques nacionales permanecieron como pastizal libre y continuo su disminución en productividad. El progreso se realizó aplicando la tecnología del comportamiento animal para mejorar la uniformidad de utilización del forraje del pastizal. Esto fue especialmente aparente en relación con ovinos y caprinos con los que se formaron rebaños en los pastizales. Las herramientas de manejo utilizadas fueron técnica de formar hatos, distribución de saladeros y el desarrollo de aguajes. La recuperación de la productividad del pastizal y el lugar de los fuegos naturales en los ecosistemas de pastizal permanecieron como temas muy controversiales.

The first 2 decades of the 20th century saw the birth of science as a tool for the management of the western range (Young 2000). By the 1920s range research had grown sufficiently, that it is impossible to comprehensively cover a decade of specific topical or regional research in a single journal manuscript. Our purpose is to portray the status of the range livestock industry and how the science of range management was shaped in its development by the perceived problems of the decade. To accomplish this portrayal we will discuss specific issues and events that highlighted the period. The 1920s are an artificial subdivision of the history of range science, so we will refer back to earlier decades and project into the 1930s on some issues.

Range Science Literature In The 1920s

Practical range management and the underlying scientific concepts that supported such management began to emerge in the period after 1900. F. E. Clements' *Plant Succession: An Analysis of the Development of Vegetation* was published in 1916. It was to have a profound influence on the development of range science. Will C. Barnes (1913) published *Western Grazing Grounds* which certainly served as a guide book for novice forest rangers if not a text for range education. Barnes (1926), as Assistant Forester and Chief of Grazing, Forest Service, United States Department of Agriculture (USDA), also compiled *The Story of The Range* which was the result of hearings held by the Senate Committee on Public Lands and Surveys of the 69th Congress. This is an excellent assessment of the status of rangelands in the mid 1920s and served as a precedent for the more comprehensive and influential *The Western Range* carried out a decade later (Anon. 1936). Published as a long and detailed USDA bulletin, Range Management on the National Forest by Jardine and Anderson (1919) provided the first handbook for practical range management. A major threshold in range science was crossed with the trilogy of text books published by Arthur W. Sampson (see Young 2000 for biographical information on Sampson).

Arthur W. Sampson

The USDA, Forest Service established its first range experiment stations in the Great Basin with A. W. Sampson as director. Before becoming the director of the initial research station, Sampson had conducted research on restoring degraded subalpine sheep ranges in northeastern Oregon.

Sampson was the most prolific range scientist of the first 2 decades of the 20th century, communicating through USDA bulletins, popular articles and an occasional scientific journal article as his medium of communication (Young 2000). He left the USDA, Forest Service during the early 1920s and became a professor of range management in the School of Forestry at the University of California at Berkeley. A major publication of his

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Forest Service research, Grazing Periods and Forage Production on the National Forest, did not appear until the mid 1920s (Sampson and Malsten 1926). His trilogy of text books were: *Range and Pasture Management* (1923), *Native American Forage Plants* (1924), and *Livestock Husbandry on Range and Pasture* (1928). His forte was the ability to apply knowledge of the plants and animals to manage an agricultural production system based on rangeland resources.

In succeeding decades, as range management grew to encompass all aspects of multiple use management from agronomy to wildlife, the basic goal of the science has become somewhat ill defined and fuzzy. In the founding days of the 1920s, the purpose of range management was to enhance meat and wool production systems based on rangelands.

Sampson's text books on plants and range management were natural outgrowths of his numerous previous publications while he was a scientist with the Forest Service. Because the Forest Service did not conduct research on livestock production, the third text book on livestock production was somewhat a venture into a new field, but obviously a venture that he thought was necessary for the education of future range resource managers. The lack of direct experimental experience with livestock was apparently true in Sampson's case, but not for all early Forest Service range scientists. The Great Basin station was followed by the Jornada and Santa Rita experimental ranges in the southwest. The Jornada Grazing Reserve was established in May 1912 by Presidential Executive Order. In 1915 it became a non-Forest (not located on a National Forest), Forest Service Experiment Station and conducted, in cooperation with the grazing permittee, animal husbandry research (Jardine and Hurtt 1917). Forest Service scientists such as Jardine, Fleming, Chapline, and Forsling, who all spent time at the Jornada, were exposed to animal breeding and nutritional research.

During the 1920s, students in range management classes were primarily forestry majors. In Sampson's obituary, published in the *Journal of Range Management*, the story was related of how Sampson had to challenge unruly forestry majors, who were un-willing participants in his range management class, to a fist fight in order to get their attention (Anon. 1968).

Growing Cast Of Range Scientist

James T. Jardine was the first director of Forest Service range research (Office of Grazing Studies) (Rowley 1985). He conducted research on range sheep grazing in the Wallowa Mountains of Oregon and worked on increasing beef production at the Jornada Grazing Reserve before moving to Washington, D.C. He resigned in 1920 to become Director of the Oregon Agricultural Experiment Station and was replaced by W. R. Chapline.

The Jornada Range Reserve was first under the supervision of Elmer O. Wooton (Anon. 1944). In 1915, non-National Forest range research was transferred from the USDA's, Bureau of Plant Industry to the Forest Service. Charles E. Fleming became the Forest Service scientist at the Jornada. Fleming was born in Odgen, Utah in 1889. He received a B. S. degree from Utah Agricultural College and a B. S. A. degree from Cornell University. He was appointed a grazing examiner for the Forest Service in 1910. After conducting research at the Jornada and Santa Rita Grazing Reserves, Fleming joined the department of range management at the University of Nevada.

Clarence L. Forsling worked at the Jornada before becoming director of the Great Basin Experiment Station in 1922 after Sampson left the Forest Service. Forsling was born on the family cattle ranch in western Nebraska. He graduated from the University of Nebraska in 1915. He ranked first on the list of applicants for Range Examiner in 1916 and was hired by the Forest Service. He became an assistant to Leon Hurtt who was director of the Jornada Experimental Range, followed by an assignment in Washington, D. C, before moving to the Great Basin station. Charles E. Fleming and William Ridgely Chapline were pioneers in the development of management systems for animals herded on rangelands.

Livestock Industry

In 1925, for every 100 Americans, there were 57 cows, 34 sheep, 47 hogs, and 15 horses (Sampson 1928). American average per-capita meat consumption was a staggering 69 kg (152 pounds) while the average for the 22 most developed countries was 41 kg (90 pounds). Before 1900 the average T-bone steak served in an American restaurant weighed 2.3 kg (5 pounds) (Young and Sparks 1985). The steak came from an American common or longhorn steer that was marketed at 4 to 6 years of age. By the 1920s the marketing age for steers had dropped to 2 to 3 year old "baby beef". America was a nation of meat eaters. The supply was excellent and relatively cheap. Texas was the leading range livestock state, closely followed by California.

Sampson considered the western livestock boom to have occurred from 1840 to 1900 (Sampson 1928). He thought the demand for forage had subjected vast areas to grazing, which in earlier days had not been considered suitable for husbandry of domestic livestock. The harsh winters on the Great Plains (1886) and west of the Rocky Mountains (1899) and the droughts of the southwest (starting 1893) killed an astounding number of livestock. In 1926 livestock numbers on the western range had fallen to an estimated 30% below the potential original carrying capacity because of degradation of rangeland resources by improper and excessive use (Sampson 1928). Even in the 1920s, USDA estimated that annually 1.1 to 1.4 million cattle died annually on rangelands from diseases (including plant poisoning) and an additional 0.6 to 1.4 million died from exposure. The exposure deaths were brought on by starvation.

The agricultural depression that followed World War I had a devastating influence on American farmers and ranchers. Agricultural producers were very conscious of cost. The Oregon Agricultural Experiment Station, now under the direction of James Jardine, undertook a series of studies on the cost of meat and wool production on rangelands. E. L. Potter (1925) divided the ranches of eastern Oregon into 2 geographic-economic regions. Most of the area east of the Cascade Mountains consisted of relatively small ranches that supported between 100 and 200 head. No ranches had more than 2,000 head and a very few exceeded 500 cows. During 4 months of winter the cows were kept at the home ranch where they grazed on crop aftermath and were fed hay. During the spring and fall they were grazed in fenced pastures in the foothills. Summers were spent in the high mountains either on National Forest or on range leased from timber companies. The exception to the type of operation described above occurred in what Potter called the free range counties of Oregon; Malheur, Harney, and a portion of Lake and Crook Counties located in the southeastern portion of the state.

The free range area covered some 6 million hectares (15 million acres) of which about 0.8 million hectares (2 million acres) were deeded land where ranch headquarters and hay fields were located. A small portion of the free range belonged to the State of Oregon, largely as school support sections. An astounding 0.8 million hectares (2 million acres) were abandoned homesteads that had reverted to public domain. All of the far western states had similar ownership patterns, in widely varying proportions, during the 1920s. Nevada had virtually no abandoned homestead land. Even the most naive homesteader hesitated at attempting rain fed agriculture in the deserts of Nevada, but the proportion of free range open to potential homesteading was much higher in Nevada as compared to Oregon.

Potter calculated the cost of running a brood cow for a year on the largely deeded land ranches of eastern Oregon as $21.40 and for the free range area as $16.10. The cost of hay production was lower in the free range area because it mainly was low quality material produced from native meadows compared to alfalfa (*Medicago sativa* L.) produced under irrigation in the deeded land area. The big difference in production cost was that the free range ranches did not pay taxes or grazing fees on the public domain rangeland. This had been a major issue since the ranges were first settled and was a major stumbling block in the prolonged struggle to establish some form of range management on the vacant public domain. This struggle did not end until the passage of the Taylor Grazing Act in 1934. Many ranchers in Nevada did not take advantage of opportunities to acquire title to portions of their public domain rangelands through purchase of state select school lands or stock raising homesteads because they believed the economic burden of paying taxes on these lands exceeded the value of the forage they harvested from the lands (Young and Sparks 1985). This became an economic hoax because, as E. L. Potter indicated in the 1920s, both the deeded land and free range ranchers were losing money on every steer they sold if you included in the cost of production interest on the capital investment. During the remainder of the 20th century, except for the relatively short period during and immediately after World War II, inflation in deeded land values was the only economic boom for the small range livestock operation in public land states. This had tragic results for ranches during the Great Depression of the 1930s. Once the Taylor Grazing Act was passed, the value of grazing permits was capitalized into the value of ranches, but by the late 20th century it became all too apparent that these permits were a privilege and not a right.

The value of grazing permits on National Forest was quickly recognized. Barnes (1913) wrote "The advantages of grazing stock on the national Forest are so apparent that the permit has come to have a great pecuniary value, resulting in a premium on both ranches and stock located within or adjacent to National Forest ranges."

The Role Of Fire

Looking back on the first half of the 20th century, it is puzzling why Americans lacked the consensus and the will to come to grips with a policy for the scientific management of the Public Domain that was not regulated by the Forest Service. The management or lack of management of these lands was widely discussed in the press. Glenn Bennion (1924), writing in The National Wool Grower stated, "Sagebrush came when the wasteful, destructive methods of range exploitation, developed as a result of the Government's indefensible free-range policy, destroyed the grass, thus permitting those forms of vegetation that stock canot eat to take the place of grass." Bennion was a resident of Utah and the member of a pioneer ranching family. We found a copy of this article in the files of the late Joseph Robertson. Dr. Robertson was noted for the comments he penciled in the margins of publications. Opposite the above quote from Glen Bennion, appeared the pencil note, "Remember this is a stockman writing, not some of those USDA so & sos." Bennion proceeded to take pioneer stockmen to task for their unknowing destruction of bunchgrass ranges by prolonged (repeated year after year), season-long, excessive grazing.

Bennion had a simple plan for the restoration of degraded bunchgrass ranges. Burn the ranges during the hot summer months, rest the burned areas from all grazing until the grasses had a chance to recover and then use moderate stocking rates with seasonal, managed grazing. He offered evidence these ranges still supported remnant stands of native perennial grasses that were available to re-stock the stands if given a chance to recover free from brush competition and excessive grazing. Mr. Bennion's article appears to have been a reasonable account of the situation that existed on many foothill ranges in the big sagebrush (*Artemisia tridentata* Nutt.) zone during the 1920s. However, the next issue of The National Wool Grower featured a letter from C. L. Forsling, Director of the Great Basin Experiment Station of the USDA, Forest Service which went to some length describing the terrible hazards associated with the use of fire in natural resource management. His concluding remarks were, "Generally speaking, fire is an uncertain doctor with a cure more to be avoided than the disease." (Forsling 1924).

Very early in his career, Arthur W. Sampson wrote a letter to the editor of the *Breeder's Gazette* where, in a near poetic style, he passionately described the evils of wildfires. "A picture more gorgeous than the stately virgin forest of pine spruce, and hemlock, studded with their refreshing glades of green and carpets of gay flowers, was the panorama that greeted the eye at the hill's summit. There in the distance below the tops of the trees were veiled with a white downy sea of smoke clouds whose outlines quickly lost their identity as they ascended" (Sampson 1911). After this introduction Sampson developed a quite academic discussion of types of forest fires including 3 excellent illustrations. Sampson signed the letter as Arthur W. Sampson, District of Columbia. The previous year he had submitted a letter to the editor of the same journal attacking the burning of prairie meadows in Nebraska, aboriginal burning before European contact, and stated the entire west was burning (Sampson 1910). He indicated his return address for this letter as Wallowa, Oregon. It is apparent that at the time, the pioneer range scientist considered wildfires a great evil. More importantly, it is apparent that the basic role of wildfires as a stand renewal process and in nutrient cycling were not understood and appreciated.

Forsling (1924) suggested there were other ways more acceptable for restoring degraded rangelands than using prescribed burning. Arthur W. Sampson (1920) had previously published in the National Wool Grower an article on how to bring back overgrazed range through grazing management. Sampson introduced the concept of deferred and rotation grazing to restore grass to overgrazed range. He stressed that hundreds of artificial seeding trials had been conducted on degraded rangelands with exotic forage species with scant success. In contrast to these failed attempts, grazing management to allow the native grasses to produce seed and establish seedlings was very successful. Sampson's research was largely conducted in subalpine grasslands. The sites Bennion was describing were degraded big sagebrush/bunchgrass sites. Sampson's basic ecological parameters applied to the big sagebrush site, but only after the dominance of the over abundant woody species was reduced. Once sagebrush had increased in abundance, it largely closed the site to perennial grass seedlings for a prolonged period of time, perhaps for 100 years in the absence of fire.

Season Of Use

The classic early paper on proper season of grazing was *Grazing Periods and Forage Production On The National Forest* by Sampson and Malmsten (1926). As previously mentioned, this Forest Service bulletin did not appear until after Sampson had moved to the University of California. This paper related the physiology of perennial grasses to damage from grazing. Grazing in the early spring before the grasses had the opportunity to renew carbohydrate reserves and flower was very harmful to the persistence of the grasses. C. L. Forsling (1928) expanded on these findings in an article published in a livestock magazine under the title of *The Spring Range Problem*. Forsling considered that in the mountain and intermountain states of the western United States, spring ranges were generally in poor condition. Much of what previously had been used as spring range was now under cultivation. Farmers wanted the livestock off the fields as soon as possible in the spring so they could conduct necessary agronomic practices such as spring-tooth harrowing alfalfa, brushing (spreading) cow chips and irrigation. Forsling suggested that special pastures should be developed to provide forage during this early spring period. The exotic perennial wheatgrasses (*Agropyron* spp.) were introduced 2 decades later and sometimes used to fill this forage need, but the problem of early spring forage remains on many former sagebrush/bunchgrass rangelands.

Range Sheep

Management on the western range continued to suffer in the first 2 decades of the 20th century from the range sheep syndrome. This syndrome blamed everything wrong with forest and range condition on the range sheep industry. The origins of the syndrome date back into the 19th century when the original Forest Reserves were established. Established cattle ranchers were quick to blame all the evils of range degradation on the range sheep and especially on so called tramp sheep operations whose owners did not own commensurate property in a given area of rangeland.

During his review of the Cascade Forest Reserve in Oregon in the 1890s, Frederick Coville of USDA was astounded to find range sheep being closely herded on the range in bands of 1,000 to 2,000 animals (Coville 1898). He blamed trampling damage from sheep for much of the destruction apparent to forested rangelands. After the Forest Service was established and became responsible for the management of Forest Reserves, experiments were conducted with predator proof fencing of timbered rangelands with the objective of grazing sheep without herders or concentration of the animals into bands (Jardine 1910).

The Forest Service appointed a series of range management staff officers for Regional Forests in 1911. For what was then called the Rocky Mountain Region, C. E. Fleming was appointed. Fleming was among the very first to apply livestock management techniques to the perceived problems created from herding sheep on rangelands. Fleming (1915) reported in the National Wool Grower on the "blanket" system of sheep handling practiced in the Madison National Forest of Montana. For a producer's magazine, the article was quite technical with scientific names given for all the plants mentioned. There were no literature citations, but at the time there was virtually no applicable literature to cite. Fleming did mention the studies conducted by Jardine at Billy Meadows in the Wallowa Mountains of Oregon (Jardine 1910). Fleming interpreted Jardine's results as indicating that carrying capacity increased 50% with free ranging versus closing herding of sheep. Based on this information, Fleming developed what he termed, at various times, the blanket, tepee, or bedding-out of handling sheep on the Madison National Forest of Montana.

The "blanket" or "tepee" designation for the grazing system developed by Fleming, apparently was derived from the herder carrying his bedroll and a canvas tent fly with him daily (Figs. 1 and 2). The key points of the system were: 1) the herder camped where the sheep ended each day and he did not return to the same camp daily, 2) during the day the sheep were allowed to graze peacefully in open bands, and 3) dogs were not used during the grazing period. The herders had to be paid $50 dollars per month, double the normal $25.00, because of the limited use of dogs and the hardship of no fixed base camp. Fleming described the ideal day as the sheep starting to graze at 0400 to 0500 hours and resting in the shade of timber during the mid-day heat or in the *browse along stream banks.*

To set the stage for his report to the wool growers, Fleming suggested that the guaranteed open summer range of the National Forest was the potential salvation of the range sheep industry. So much of the previously open range in the plains and foothills of Montana was lost to the sheep industry because of homesteading.

Range Goats In The Southwest

At nearly the same time that Fleming was developing new sheep management methods in Montana, Forest Service scientists were developing management procedures for goat grazing in the National Forest of the southwest. It was estimated that 50,000 goats grazed on the National Forest of New Mexico and Arizona in 1916 (Chapline 1916). In many portions of the west, ranchers were noticing the condition of ranges was changing. The most common perception was the decrease in herbaceous vegetation, especially perenni-

Fig. 1. Illustration of one-night sheep camp where herder pitched his tent where ever the sheep stopped at the end of the day rather than returning to a fixed camp every night. (Fleming 1918).

Fig. 2. Illustration of relaxed or open herding of sheep on the range to prevent trampling damage. Herd directed by turning the leaders rather than dogging the tail end of the band (Fleming 1918).

al grasses, and increased dominance by woody vegetation. This perception led ranchers to write letters to editors of newspapers and commodity periodicals describing the losses in forage production and usually calling for the return of burning to National Forest, or more precisely, the end of fire suppression in National Forest.

In the southwest, a different scenario of this increase in brush theme was unfolding. Goat ranchers were sure the answer to increased brush was increased browsing by goats. In 1916 the editor of *The Angora Journal* published an editorial chastising the Forest Service for not allowing increased goat grazing on the National Forest (Chapline 1916). This prompted Acting Forester A. F. Potter to respond to the editor that the Forest Service was studying goat management and he submitted a manuscript from the Forest Service scientist W. R. Chapline, Jr. to illustrate this research.

Chapline had the longest professional career of the early range scientists. He was born in Lincoln, Nebraska in 1891 and graduated from the University of Nebraska. He progressed from grazing assistant to range examiner with the Forest Service before becoming Director of the Office of Grazing Studies. Chapline was at the Jornada Experimental Range the day Poncho Villa raided across the border into New Mexico.

Chapline made the same management suggestions for goats that had previously been made by Fleming for sheep (Chapline 1916). He called his systems a "several camp" versus the traditional "one camp" method of herding. Chapline (1919) later expanded this manuscript into USDA Bulletin No. 749, which became one of the cornerstone papers of range management.

In the same issue of *The Angora Journal* a letter appeared from a goat rancher under the headline "Forest Officials Discriminate Against Goat Growers, But Favor Cattle Operations" (Anon. 1916). On the Gila Forest, goat numbers had been reduced from 47,100 to 23,800 while cattle numbers had been allowed to increase. The same rancher complained that since the National Forest was established, wherever he rode on the range there were signs telling him how to prevent wildfires, but there were no signs on how to manage the forage resource.

One-Night Camps

C.E. Fleming left the Forest Service to become the head of the Department of Range Management at the University of Nevada. He published 2 bulletins on range sheep management, with the same title "One-Night Camps vs. Established Bed-Grounds On Nevada Sheep Ranges" (Fleming 1918, 1922). Note that he had dropped his "blanket" or "tepee" management and adopted Chapline's 1-night designation for preferred management. Fleming based his bulletins on actual experimentation. He described the experimental area as nearly tree-less mountain ranges where the vegetation consisted of 75% perennial grass, 20% weeds (broadleaf native plants we would now refer to as forbs), and 5% browse. He indicated that utilization averaged an astounding 93% of the annual forage production.

Fleming made the basic comparison of established camps to which the sheep were herded nightly and the sleeping-out, 1-night system where a new camp was used every night. The nightly moving camp was only part of the contrasting system. Of more importance was the relaxed way the sheep were allowed to graze during the day, with open bunches and limited or no dogging (tightly bunching the animals with the help of sheep dogs) of the animals. Fleming measured the success of 1-night herding both in terms of reduction in trampling and over-grazing damage and in increased wool and mutton production. Vegetation sampling was accomplished by an extensive set of paired plots on bedding grounds. Using bands of 1,500 ewes and lambs each, the open herded, one-night camp band out-produced the traditional herded band by over 3,632 kg (8,000 pounds) of mutton during a summer grazing season.

In 1928 the Utah Agricultural Experiment Station published a quite comprehensive bulletin on the range sheep industry (Esplin et al. 1928). The only mention of Fleming's research was a terse sentence indicating that if you camped more than 1 night in the same place with a band of sheep on the National Forest you were going to pay penalties.

Salting

Distribution of livestock on rangelands was perceived by early range scientists as a major problem in obtaining proper grazing management. During the 1920s, most of the rangeland was open with minimal fencing. Watering points were limited and expensive to develop. Topography often was a restraint on the distribution of grazing animals. For sheep and goats, modification of herding practices could be used to obtain improved distribution. For cattle and horses, their natural craving of the grazing animals for salt (sodium chloride) could be exploited to obtain improved livestock distribution (Chapline and Talbot 1926).

Obviously, there are great differences in the salt requirements for livestock in different locations in the west. On the salt desert winter ranges of the Great Basin, many of the native shrubs, such as black greasewood (*Sarcobatus vermiculatus* [Hook.) Torr.), got rid of excess salts by shunting them to deciduous fruits and leaves which livestock licked from the soil surface. On summer ranges in the high mountains, during succulent feed periods, forage would be deficient in salt. The issue in livestock management was not so much a problem in dietary deficiency as it was the craving livestock exhibited for sodium chloride and the potential this craving offered for modifying animal behavior. Chapline and Talbot (1926) placed salting in the perspective that the potential benefits in improved distribution were so great and the cost of artificially provided salt licks so low, range managers were foolish not to use proper salting methods. They placed the average annual salt requirement for cows at 20 pounds, and sheep and goats 3 to 4 pounds.

The natural tendency among stockmen was to place the salt where the livestock concentrated at watering points. This was based on the assumption that the animals needed the supplement so it should be placed where it could be easily found. This essentially enhanced the concentration of livestock around watering points and therefore added to the over utilization of vegetation.

Before the advent of salt pressed into blocks, the only stock salt available was the coarse ground "hay" salt, so called because farmers used it to prevent the spoilage of hay with excessive moisture content. Rock salt could be used, but it was injurious to the teeth and mouths of livestock. The losses from moisture and wildlife use of coarse ground salt, meant that ranchers had to have cowboys riding a salting circuit virtually the entire grazing season. To reduce losses of salt and to prevent the trampling and pawing damage associated with placing salt on the ground, Chapline and Talbot stressed the construction of boxes for the placement of salt. Considering the remote, roadless conditions of most National Forest rangelands, these salt logs were chopped from logs available on the site. Prospective applicants wishing to take the Civil Service test for employment as a Junior Range Examiner with the USDA, Forest Service had better be prepared on the hewing of salt logs. Pressed 50 pound blocks of salt replaced granular bagged salt. Sampson (1923) objected to the pressed blocks because of the time required for livestock to satisfy their salt needs by licking the blocks as opposed to consuming the granular salt. The blocks were also a mixed blessing for those who had to lash the dense, slippery blocks with beveled corners to a pack saddle.

The value of salting plans for enhanced livestock distribution lay in their cheapness of application and their immediate effectiveness, although they could not be expected to correct all the natural faults associated with proper livestock distribution (Jardine and Anderson 1919). As we enter the 21st century it is not very difficult to drive about anywhere on the western range and still find salt or other supplement stations located at watering points.

Stock Water

Jardine and Hurtt (1917) stressed the importance of well-planned water supplies for rangelands. On the Jornada Range Reserve they considered that cattle should not have to travel more than 2 1/2 miles for water. They reported that during the drought of 1916 cattle outside the Jornada Reserve were forced to go so far from water to find forage they arrived back at water in a weakened condition and when they returned to water they drank and died. Water was the key in obtaining even distribution of grazing.

The development of stock water in the southwest was the subject of a much more detailed treatment by M.W. Talbot (1926). He reported that ranchers and the Forest Service had spent $750,000 on the development of stock water in the 14 National Forests of the southwest. Talbot stressed that further development of water would not lead to more livestock on the National Forest, but to more even utilization of the existing forage resources and a reduction in excessive grazing near existing water.

In the southwest, ranchers usually considered about one third of their cows watered every day. This went up to 100% of the cows during hot dry weather. During periods of succulent forage, sheep could go for extended periods without water. Talbot (1926) introduced the role of topography in determining the correct spacing of watering points. On rolling topography, 1 watering point might be sufficient for 500 cows, while in steep, rugged topography one watering point would suffice for only 50 cows.

Conclusion

Obviously, range science was growing and becoming defined during the decade of the 1920s. A. W. Sampson's 3 books provided texts for range management courses in the western schools of forestry. Livestock management systems were proposed to solve the lingering problem of management of herded sheep and goats on rangelands. Modification of the behavioral patterns of range livestock with distribution of salt and watering points became foundations of range management.

Despite the advances in range science, the range livestock industry remained mired in economic depression. There was endless debate, but no agreement on who was to manage the vast areas of unappropriated public lands. There was no lack of proposals on how to dispose of or manage the unappropriated lands. The Forest Service was proposed as the management agency for these lands. Elmer O. Wooton, the pioneer botanist in New Mexico and the first director of the Jornada Grazing Reserve, became involved in Nevada with a proposal to divide the unappropriated public domain among ranchers based on the ownership of stock water sources (Young et al. 1998). Currently, Federal, versus State or private ownership of water rights on public domain remains a volatile issue.

A. W. Sampson (1928) devoted a chapter in his book *Livestock Husbandry On Range and Pasture* to wildlife resources on rangelands. This was a major departure from most of the previous range science literature. In the next decade wildlife-livestock interactions were to become a major issue. Sampson credited Joseph Grinnell (1924) with the pioneer publication on wildlife on the western range.

It is interesting to contemplate if anyone involved during the 1920s with the western range and livestock industry, had any inkling of the Great Depression, regional droughts, and social change that were waiting to occur during the 1930s.

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Paddock shape effects on grazing behavior and efficiency in sheep

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Abstract

Two grazing trials were conducted during early winter (December 1996–January 1997) and spring (April–May 1997) to evaluate the effect of shape of pasture on forage use and behavior of grazing sheep (*Ovis aries*). Two treatments were tested, square and rectangular paddock, with 2 replicates for each treatment of 9 ewes each. Groups were homogeneous for age and weight. Paddock size furnished 10 m^2 per sheep per day. Each paddock was divided into 8 equal plots to determine herbage intake and grazing efficiency along the boundary and in the middle of paddocks. The shape of paddock affected sheep grazing efficiency and herbage intake both in the winter and in the spring. Because of a greater amount of herbage destroyed within boundary plots, the ewes in rectangular paddocks grazed less time, had lower herbage intake and used forage less efficiently than ewes in square paddocks. These results suggest that the shape of pasture can affect the behavior and herbage intake of sheep grazing in small paddocks and indicate that square paddocks should be used for research studies on sheep grazing behavior.

Resumen

Se condujeron dos experimentos de apacentamiento durante inicios de invierno (Diciembre 1996 - Enero 1997) y primavera (Abril-Mayo 1997) para evaluar el efecto de la forma del potrero en el uso del forraje y el comportamiento de apacentamiento de los ovinos (*Ovis aries*). Se probaron dos tratamientos, potreros rectangulares y cuadrados. Se tuvieron 2 repeticiones por tratamiento de 9 borregas cada una, los grupos de borregas eran homogéneos en edad y peso. El tamaño del potrero suministró 10 m^2 por borrega día-1. Cada potrero se dividió en 8 parcelas de igual tamaño para determinar el consumo de forraje y la eficiencia de apacentamiento a lo largo de las orillas y en la parte central del potrero. La forma del potrero afectó la eficiencia de apacentamiento y el consumo de forraje tanto en invierno como primavera. Debido a que una mayor cantidad de forraje se destruyó dentro de los limites de las parcelas, las borregas en los potreros rectangulares apacentaron menos tiempo, tuvieron un consumo menor de forraje y utilizaron menos eficientemente el forraje que las borregas de los potreros cuadrados. Estos resultados sugieren que la forma del potrero puede afectar el comportamiento y consumo de forraje de los ovinos apacentando potreros pequeños e indican que los potreros cuadrados deben ser usados para estudios de investigación sobre el comportamiento de apacentamiento de ovinos.

Key Words: diet choice, space pattern, grazing management

There is evidence that feeding behavior of grazing sheep (*Ovis aries*) is largely affected by environmental conditions (Arnold and Dudzinski 1978, Bueno and Ruckebusch 1979, Dudzinski and Arnold 1979), sward characteristics (Penning et al., 1994) and endogenous factors, such as physiological state (Penning et al. 1995), breed (Arnold 1975, Dudzinski and Arnold 1979) and previous experience (Olson et al., 1996). Because sheep do not use space at random (Hutson, 1984) and graze differently when they are put in rectangular compared to square paddocks (Lynch and Hedges, 1979), it is likely that paddock shape can influence forage use and feeding behaviour of sheep on pasture. Lange (1985) has shown that in a small paddock of high quality improved pasture the stocking intensity of various parts of the paddock varied from one-eighth to 8 times the paddock average stocking rate. In housed ewes, Sevi et al. (1996) found an effect of the shape of pen on space use, the square pens resulting in more uniform use of space than the circular and the triangular pens. Thus, research studies on sheep grazing behavior, which often use small flocks and paddocks with the expectation that the knowledge of factors controlling voluntary intake can be generalized, may be vitiated by overlooking the aspects of grazing behavior which are related to the utilization of space in small paddocks.

The present study was undertaken to investigate the effects of paddock shape on forage use by grazing sheep. Two trials were performed during the winter and the spring seasons to assess the impact of paddock shape on sheep feeding activity with respect to different climatic conditions and level of supplementation.

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Materials and Methods

The experimental site was approximately 20 kilometers northwest of Foggia, Apulia, Southern Italy (latitude: 41° 27' 6" and longitude: 15° 33' 5"), with an elevation of about 100 meters above sea level. The climate of this area is Mediterranean. Ambient temperatures, recorded at the meteorological station of the Capitanata Land-Reclamation Syndicate (3.5 km away from the site of experiment), ranged from –5.8 to 18.5°C during the winter trial and from –3.5 to 33.8°C during the spring trial. Averages of relative humidity, sun radiation and wind speed were 79.4%, 55.4 W/m^2 and 2.2 m/sec in winter and 61.1%, 215.8 W/m^2 and 2.9 m/sec in spring.

The study pasture was composed of Graminaceae (*Lolium* spp., *Bromus* spp., *Festuca* spp.) and to a smaller extent of Cruciferae (*Eruca sativa* L.), Compositae (*Carlina corymbosa* L., *Cirsium* spp.) and Leguminosae (*Medicago* spp., *Trifolium* spp.). The above mentioned botanical families were nearly always distributed in very complex mixes.

Grazing trials were conducted during early winter (December 1996 to January 1997) and spring (April to May 1997) using dry Wurttenberg x Ile de France x Gentile di Puglia ewes. Both trials lasted 30 days and were divided into three, 10-day grazing periods. Upon their arrival at the experimental site, the ewes were subjected to a 7-day acclimation period so they could become acquainted with their peers. During this period the sheep were allowed to graze similar pastures adjacent to the experimental pastures.

Two treatments were tested, square paddock (SP) vs rectangular paddock (RP) with 2 replicates of 9 ewes for each treatment at each season. The ewes of the experimental groups were homogeneous for age (3.5 years) and weight (approximately 65 kg). Paddock size was 900 m^2 (30m x 30m for square paddocks and 75m x 12m for rectangular paddocks) to maintain a constant area of 10 m^2 per sheep per day. Daily forage allowance was 1.34 and 1.31 kg DM/ewe/day at the beginning of the winter trial and 1.95 and 1.91 kg DM/ewe/day at the beginning of the spring trial for rectangular and square paddock treatments, respectively. Herbage composition was very similar among the experimental groups. Paddocks were contiguous with mesh-fence boundaries. The groups of animals were somewhat isolated visually by rows of almond trees. Paddock boundaries were about 50 m away from the road leading to the farm, so we consider that groups experienced the same amount of stimuli from the surrounding environment. Every day the ewes grazed from 0800 to 1600 hour in the winter and from 0900 to 1700 hour in the spring and spent the rest of the day in separate straw-bedded pens. When the ewes returned to their own pens they were given vetch/oat hay (1.0 kg in winter and 0.5 kg in spring per head) and wheat-bran (0.25 kg per head in winter).

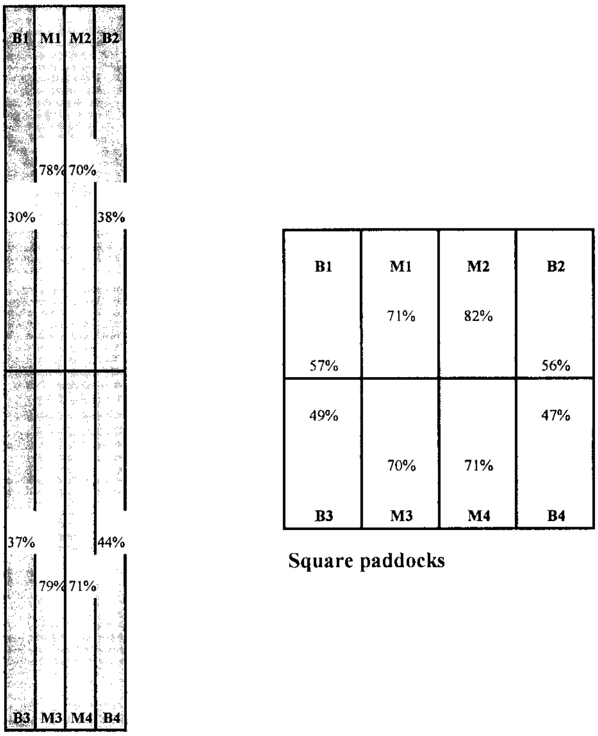

Fig. 1. Paddock splitting in boundary (B) and middle (M) plots. Percentages are treatment mean utilization efficiency for each plot in square and rectangular paddocks (drawings are to scale of 1:750).

Measurements

Forage mass and composition were determined before and after each 10 day grazing period. To assess the utilization of boundaries compared to interior areas, paddocks were divided into 8 equal size plots (about 110 m^2 each), 4 along the boundaries and 4 in the middle of paddocks (Fig. 1). In each plot, 2 herbage samples were harvested to ground level within 2 randomly selected 1 m^2 quadrates. The forage samples were oven dried at 50°C for 48 hours, and dry weights were recorded. Herbage samples, as well as hay and wheat-bran samples (Table 1), were analyzed for fat, crude protein, crude fiber and ash (AOAC 1990). Average daily forage and nutrient intake was calculated as the difference between pre-grazing and post-grazing forage mass divided by the number of ewe days of grazing in the paddock. Post-grazing forage mass was adjusted for the amount of growth during each period using estimates of pasture growth derived from cutting 16 randomly selected 1 m^2 quadrates in adjacent ungrazed pasture at the beginning and the end of each grazing period. Pasture utilization efficiency (PUE) was calculated as the ratio of herbage intake to herbage availability.

Table 1. Chemical composition and nutritional value of the whole herbage, hay and wheat-bran.

	Whole herbage		Vetch/ oat hay	Wheat-bran
	Winter	Spring		
Dry matter (%)	23.1	21.0	83.4	89.2
Crude protein (% DM)	15.1	17.7	12.8	17.6
Fat, by ether extract (% DM)	2.8	3.5	1.2	3.7
Crude fibre (% DM)	23.8	21.0	31.0	13.7
Ash (% DM)	10.3	10.9	9.1	6.7
N-free extract (% DM)	46.0	44.9	45.9	58.3
Gross energy (MJ/kg DM)	20.1†	20.3†	18.1†	19.0††

†Evaluated according to the equation by Lanari et al. (1993). †† Evaluated according to the equation by Schiemann et al. (1971).

Table 2. Estimated dry matter (DM), crude protein (CP) and gross energy (GE) intake and pasture utilisation efficiency (PUE) for ewes in square and rectangular paddocks in winter and spring.

	Winter							Spring						
	Square paddocks			Rectangular paddocks			SE	Square paddocks			Rectangular paddocks			SE
Parameters	Herb	Supp.	Total	Herb.	Supp.	Total	Herb.	Herb.	Supp.	Total	Herb.	Supp.	Total	Herb.
DM intake (kg/ewe/day)	0.77a	1.06	1.83	0.68b	1.06	1.74	0.01	1.30a	0.42	1.72	1.11b	0.42	1.53	0.01
CP intake (g/ewe/day)	139b	146	285	121b	146	267	5.50	272a	53	325	234b	53	288	2.61
GE intake (MJ/ewe/day)†	19.4b	19.3	38.7	19.2b	19.3	38.5	0.09	21.1a	7.5	28.6	20.6b	7.5	28.1	0.06
PUE (%)	58b			52b			1.54	67a			58b			0.72

†Evaluated according to the equation by Lanari et al. (1993). SE, standard error. For each season, means of pasture parameters within the same line followed by different letters are significantly different at P < 0.05.

Herbage destruction index (HDI) was calculated as the ratio of herbage destroyed (i.e. covered by manure or trampled by sheep) to herbage available.

The grazing behavior of the ewes was recorded 3 times during each grazing period (on the 3rd, 6th and 9th day) by 3 trained observers equipped with video cameras. Behavioral observations were conducted from 0900 to 1700 hour and were divided into 60 min periods for each group. A different focal animal was chosen at random every day in each group, and the 60 min observation periods were systematically rotated among treatments and replicates. Times spent eating, ruminating, standing inactive, resting, walking, defecating and urinating, exploring, and in other activities (self-grooming, grooming, scratching oneself, bleating, fencing biting) were recorded.

Statistical Analysis

Pasture and behavioral variables for each season were subjected to analysis of variance for repeated measures (SAS 1990), with shape of paddock as a non-repeated factor and time and shape of paddock x time as repeated factors. Pasture variables were also processed with paddock plot (boundary or middle) as source of variation. When significant effects were found, the Student T test was used to determine differences (P < 0.05) between means.

Results and Discussion

The data on herbage intake and pasture utilization efficiency are reported in Table 2. The ewes in the rectangular paddocks had significantly smaller herbage intakes and lower pasture utilization efficiency both in the winter and in the spring. The shape of paddock did not significantly affect nutrient intakes in the winter, but protein and gross energy intakes were greater in the square paddocks than in the rectangular paddocks in the spring.

Herbage intake and pasture utilization efficiency were affected significantly by the interaction of paddock shape and plot location in a paddock. The amounts of herbage consumed by the square and rectangular paddock ewes were very similar in the middle of the paddocks, but the ewes in the rectangular paddocks had significantly smaller herbage intakes within the boundary plots (Table 3). This was caused by a greater amount of forage being destroyed and reduced pasture utilization in the boundary compared to middle plots (Fig. 1). The amount of herbage destroyed was 42% higher in the rectangular as compared to the square paddock boundary plots. Relative to the boundary length, the ewes in the rectangular paddocks destroyed proportionately less herbage than those in the square paddocks, but this is not surprising because the square paddock ewes had a 40% higher herbage intake and, consequently, a greater feces output with respect to the rectangular paddock ewes.

In both trials, grazing sheep spent a large part of the time (50 to 71%) eating (Table 4). The ewes in the rectangular paddocks exhibited significantly lower eating times than those in the square paddocks both in the winter and in the spring. In contrast, the ewes in the rectangular paddocks walked and explored more than those in the square paddocks.

There is evidence that certain features within an environment may change the space available to inhabitants (Siegel and Gross 1973) and corners or perimeters (i.e., shape) may vary the conceptual space of an area (Stricklin et al. 1979). It is well known that sheep spend a long time in exploring any new field they are put in and pay most initial attention to the field boundaries (Fraser and Broom 1990). In addition, settling down in a group along the field boundaries and corners has been described as a species-typical feature in sheep (Hutson 1984, Fraser and Broom 1990). Time spent in an area is proportional to the feces deposited by the sheep as they visit that area (Arnold 1981). Thus, taking into account that rectangular paddocks had 145% the perimeter of square paddocks, increased amount of forage destroyed by grazing ewes might be explained with some species-typical features of sheep, such as long-time walking, exploring and resting along the field boundaries, which are enhanced by higher perimeter to area ratio. In paddocks ranging from 70 to 900 m^2 Ali and Sharrow (1994) found that the amount of forage destroyed by sheep is markedly higher during the early stages of grazing, decreases during the middle stages and often rises again in the later stages of grazing cycles. This suggests that higher amount of forage destroyed along boundary areas of rectangular paddocks might be primarily dependent on increased trampling by walking and exploring ewes during the early stages and on manure accumulation during the later stages of grazing periods. Increased

Table 3. Estimated herbage intake, pasture utilisation efficiency (PUE) and herbage destruction index (HDI) for ewes in square and rectangular paddocks in winter and spring.

	Boundaries		Middle		
Parameters	Square paddocks	Rectangular paddocks	Square paddocks	Rectangular paddocks	SE
Herbage allowance (kg DM/ewe/day)	1.64	1.62	1.65	1.60	0.02
Herbage intake (kg DM/ewe/day)	0.86b	0.60c	1.21a	1.19a	0.01
PUE (%)	52b	37c	73a	74a	0.92
HDI (%)	26b	37a	17c	19c	0.61

Means within the same line followed by different letters are significantly different at P < 0.05.

Table 4. Grazing behaviour of ewes in square and rectangular paddocks in winter and spring.

Parameters	Winter Square paddocks	Winter Rectangular paddocks	SE	Spring Square paddocks	Spring Rectangular paddocks	SE
	(% of total grazing time).					
Eating	58.6a	49.6b	1.3	71.0a	63.9b	1.4
Ruminating	7.1	6.7	0.5	7.5	8.0	0.6
Standing	3.5b	5.5a	0.4	3.4b	5.0a	0.3
Resting	15.0	14.2	0.4	9.5	9.4	0.2
Walking	6.9b	12.5a	0.9	3.9b	6.7a	0.7
Defecating+urinating	2.1	1.6	0.6	1.3	1.1	0.5
Exploring	3.7b	6.0a	0.4	2.3b	4.4a	0.3
Other activities	3.1	3.9	0.9	1.1	1.5	0.5

For each season, means within the same line followed by different letters are significantly different at $P < 0.05$.

amount of herbage destroyed can further enhance time spent in locomotion and exploration via the reduction in forage availability, which results in increased walking and exploring of the ewes searching for food (Gluesing and Balph 1980). This may explain why time spent in these activities was about 25% higher than the difference in perimeter between the rectangular and the square paddocks.

Conclusions

Although this study has little practical application for grazing management, due to small flock and paddocks used, it should be important to researchers who study voluntary feed intake or diet choice in sheep. Our findings suggest that the shape of pasture can affect the behavior and herbage intake of sheep grazing in small paddocks. This indicates that the choice of an appropriate paddock shape is required for research studies on sheep grazing behavior which generally uses small flocks and small paddocks. Under the conditions of this study, rectangular paddocks resulted in less efficient use of forage as compared to square paddocks and the greater amount of herbage destroyed along the paddock boundaries was primarily responsible for reduced intake of sheep in rectangular paddocks.

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Cover for wildlife after summer grazing on Sandhills rangeland

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Abstract

Livestock production and wildlife habitat objectives become antagonistic on grasslands when the architecture of standing herbage needed for key wildlife species limits the amount of forage that can be used by livestock. However, quantitative information needed to achieve cover objectives for wildlife is not available for summer-grazed grasslands. Three replicates of 7 grazing treatments were applied to the same 1.0-ha pastures for 3 years. Treatments included ungrazed control, and grazing at 16, 32, or 48 animal unit days (AUD) ha^{-1} for 5 to 7 days during mid-June or mid-July. Cover was estimated after killing frost in September by measuring the average height below which complete visual obstruction occurred. Cumulative grazing pressure (AUD Mg^{-1}) was used to describe grazing effects because of measurable differences in herbage among pastures and dates. Grazing in June reduced the average height of autumn cover at a constant rate from 11.0 to 7.0 cm (R^2 = 0.34) as cumulative grazing pressure increased from 16 to 90 AUD Mg^{-1}. In contrast, declines in cover after grazing in July were about 2.6 times greater for cumulative grazing pressures up to 40 AUD Mg^{-1} (R^2 = 0.62), indicating a measurable decline in plant growth and an increasing dependence of autumn cover on the remaining herbage when grazing ended. Relatively low predictability of autumn cover after June compared to July grazing was offset by more plant growth during the balance of the growing season. Frequency of low-cover patches (≤ 5.0 cm) within pastures was highly correlated (R^2 = 0.94) with mean estimates of autumn cover. Consequently, the quality of cover near potential nesting sites also declined as the average height of cover declined, regardless of grazing date. The interdependence of low-cover patches and mean visual obstruction indicates that either variable could be the primary criterion for nest site selection up to 12 cm in visual obstruction.

Key Words: autumn visual obstruction, grazing pressure, sharp-tailed grouse (*Tympanuchus phasianellus*) habitat

Resumen

Los objetivos del manejo del hábitat para la fauna silvestre y la producción de ganado vienen a ser antagónicos cuando la arquitectura de la vegetación en pie necesaria para las especies clave de fauna silvestre limita la cantidad de forraje que puede ser usada por el ganado. Sin embargo, la información cuantitativa necesaria para alcanzar los objetivos de cobertura para la fauna silvestre no esta disponible para pastizales de verano. Durante 3 años, 3 repeticiones de 7 tratamientos de apacentamiento se aplicaron en los mismos potreros de 1.0 ha. Los tratamientos incluían el control sin apacentamiento y el apacentamiento a 16, 32 y 48 unidad-animal-días (UAD) ha^{-1} por 5 a 7 días a mediados de junio o mediados de julio. La cobertura se estimó después de la primer helada de septiembre midiendo la altura promedio abajo de la cual ocurrió la obstrucción visual completa. Se utilizó la presión de apacentamiento acumulativa (UAD Mg^{-1}) para describir los efectos del apacentamiento debidos a diferencias medibles de forraje entre potreros y fechas. El apacentamiento en Junio redujo la altura promedio de la cobertura de otoño a una tasa constante de 11 a 7 cm (R^2 = 0.34) conforme la presión de apacentamiento acumulativa se incremento de 16 a 90 UAD Mg^{-1}. En contraste, las disminuciones de cobertura después del apacentamiento en Julio fueron cerca de 2.6 veces ma para las presiones de apacentamiento acumulativas hasta de 40 UAD MG^{-1} (R^2 = 0.62), indicando una disminución medible en el crecimiento de las plantas y una dependencia en aumento de la cobertura de otoño en el forraje remanente cuando el apacentamiento termino. La relativamente baja predictibilidad de la cobertura de otoño después de Junio comparada con el apacentamiento de Julio fue neutralizada por un mayor crecimiento vegetal durante el balance de la estación de crecimiento. La frecuencia de parches de baja cobertura (#5.0 cm) dentro de los potreros estuvo altamente correlacionada (R^2 = 0.94) con la media de las estimaciones de la cobertura de otoño. Consecuentemente, la calidad de la cobertura cerca de sitios potenciales para anidamiento también disminuyó conforme la altura de la cobertura se redujo, independientemente de la fecha de apacentamiento. La interdependencia de parches de baja cobertura y la media de obstrucción visual indica que cualquier variable puediera ser el criterio principal para la selección de sitios de anidamiento hasta de 12 cm en obstrucción visual.

The relationship between livestock and rangeland wildlife habitat is dynamic. Herbage is the primary source of nutrients for livestock and the only source of nesting cover for many grassland bird species. Herbage allocation decisions are important each year. Standing herbage after grazing and plant growth during the balance of the growing season are the only sources of cover when birds search for nesting sites early in the following spring. The quality of nesting cover on grasslands declines as stocking rate increases (Duebbert et al. 1986, Kie et al. 1996). Grazing management strategies that provide adequate cover for establishment

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of successful nest sites in early spring increase mean clutch size of many grassland bird species (Kantrud and Higgins 1992, Fredrickson 1996) and allow chicks to develop before peak summer heat stress and mature before harsh fall weather conditions occur. Cumulative grazing pressure, date of grazing, precipitation, and kind and distribution of plant species are important variables in understanding the effects of grazing management decisions on cover for wildlife (Schroeder and Braun 1992). However, there is no published quantitative information that can be used to manage summer grazing to obtain target levels of autumn cover in grass dominated ecosystems.

The Sandhills of Nebraska which encompass about 3.9 million ha of native grassland, are home to the largest populations of sharp-tailed grouse (*Tympanuchus phasianellus*) in the United States. Sharp-tailed grouse and many other species of grassland birds select nest sites from late March to early June in the Nebraska Sandhills (Duebbert et al. 1986, Fredrickson 1996). Nesting and brood rearing cover are the most limiting habitat factors for sharp-tailed grouse through much of the Sandhills (Prose 1987). Our objective was to quantify the effects of grazing pressure in June or July, precipitation, and the frequency of occurrence of selected plant species on nesting cover, based on visual obstruction (VO) measurements after killing frost in September.

Materials and Methods

The study was conducted on sands range sites in good to excellent condition at the University of Nebraska, Gudmundsen Sandhills Laboratory (42° 07' N, 101° 43' W) located near Whitman, Neb. Prairie sandreed [*Calamovilfa longifolia* (Hook) Scribn.], sand bluestem (*Andropogon hallii* Hack), and little bluestem (*Andropogon scoparius* Michx.) were co-dominant species on these sites (Great Plains Flora Association 1986). The long-term, 30-yr average annual precipitation is 56 cm (National Oceanic and Atmospheric Administration 1997). Soils are Valentine fine sands (mixed, mesic Typic Ustipsamments).

Experimental units were individual 1.0-ha pastures. Twenty-one pastures were separated into 3 blocks based on frequency of occurrence of plant species in fifty, 0.25-m^2 (50 x 50 cm) quadrats randomly located in uniformly spaced belt transects in each pasture in May 1995. Occurrence of hairy grama (*Bouteloua hirsuta* Lag.), little bluestem, prairie sandreed, and sand bluestem in nested 0.05 m^2 and 0.01 m^2 areas within the 0.25-m^2 quadrat also was recorded. Seven grazing treatments were randomly allotted to pastures within each block. Treatments consisted of an ungrazed control, grazing at light, moderate, or heavy seasonal stocking rates, 16, 32, or 48 animal unit days (AUD) ha^{-1}, for 5 to 7 days in mid-June or mid-July. Grazing treatments were applied to the same pastures in each summer from 1995 through 1997. Yearling cattle were weighed after an overnight stand without food and water and allocated to treatments by weight to provide equal total weights of cattle for replications within stocking rate treatments. Animal weights were divided by 454 kg to estimate animal unit (AU) equivalents. The number of yearlings per pasture ranged from 4 to 12. Pastures in this study had previously been used for grazing research from 1988 to 1991 (Reece et al. 1996). All pastures were rested in 1992 and 1994. Pastures were stocked at 49 AUD ha^{-1} from June to October 1993.

Before grazing treatments were applied, current-year standing herbage was estimated by clipping all vegetation at ground level in ten, 25 x 100-cm randomly located quadrats per pasture. Based on repeated observations in these pastures during a previous study, Northup (1993) reported that six weeks fescue, (*Festuca octoflora* Walt.), green sagewort (*Artemisia dracunculus* L.), western ragweed (*Ambrosia psilostachya* DC.), prickly pears (*Opuntia* spp. P. Mill.), pincushion cactus [(*Coryphantha vivipara* (Nutt.) Britt. & Rose], and prairie wild rose (*Rosa arkansana* Porter) were not grazed or were rarely grazed by cattle in June or July. These species and all previous year's growth were discarded. The remaining herbage was oven dried at 60°C for 48 hours and weighed to the nearest 0.1 g to determine dry matter yield. Grazing pressure was expressed as AUDs per metric ton of current-year palatable herbage (AUD Mg^{-1}) measured at the beginning of grazing periods.

Autumn cover for birds was estimated by measuring visual obstruction (VO) in late September, after killing frost, at a randomly selected point within 48 uniformly spaced areas in each pasture. Equipment used to measure VO was similar in design to that used by Robel et al. (1970). Two, 3 x 120-cm poles were connected by a 4-m nylon cord fastened at a height of 1 m on each pole. The reading pole was painted in 36 alternating 2.54-cm wide bands of gray and white, numbered in ascending order with 1 at the bottom. The reading pole was held vertically at sample points while a second person placed the sight pole at a distance of 4 m and recorded the number of the lowest band not fully obstructed by vegetation when viewed from a height of 1.0 m on the sight pole. Means of 2 VO readings taken on the contour from opposite sides of each sample point were used for analysis.

A 2 x 3 factorial array of grazing dates and stocking rates was used to produce a wide range in cumulative grazing pressure. Ungrazed control data (n = 9) were combined with data from grazed pastures for each month (n = 27) and months were analyzed separately (n = 36) with regression analysis (SAS 1985) to evaluate the univariate effects of cumulative grazing pressure on mean visual obstruction of individual pastures. The entire data set from 21 pastures over 3 years (n = 63) was used in regression analysis to determine the relationship between frequency of low-cover patches (VO $\leq$ 5.0 cm) and mean visual obstruction in pastures after killing frost in September. Additionally, the stepwise procedure (SAS 1985) was used to conduct a regression analysis on the multivariate effects of cumulative grazing pressure, precipitation in individual or multiple months within years, and frequency of occurrence of selected grass species on visual obstruction in the autumn after grazing in June or July (n = 27) and for ungrazed pastures (n = 9).

Results and Discussion

Visual obstruction (VO) in ungrazed control pastures declined 11% from 12.3 cm in 1995 to 11.0 cm in 1996 and 15%, to 9.3 cm, from 1996 to 1997. These declines corresponded to progressively lower cumulative precipitation each year (Fig. 1). Most of the differences in cumulative precipitation among years summarized in Figure 1 occurred during May and June because differences among years were relatively small at the end of April. Measurable differences in soil moisture during May and June would cause measurable differences in current-year herbage in autumn (Dahl 1963). Similar declines in autumn cover in ungrazed control pastures from 1995 to 1996 and from 1996 to 1997 when precipitation declined 30% compared to 9% between years indicated that carryover herbage from preceding years moderated changes in cover between 1995 and 1996. Additionally, the relationship

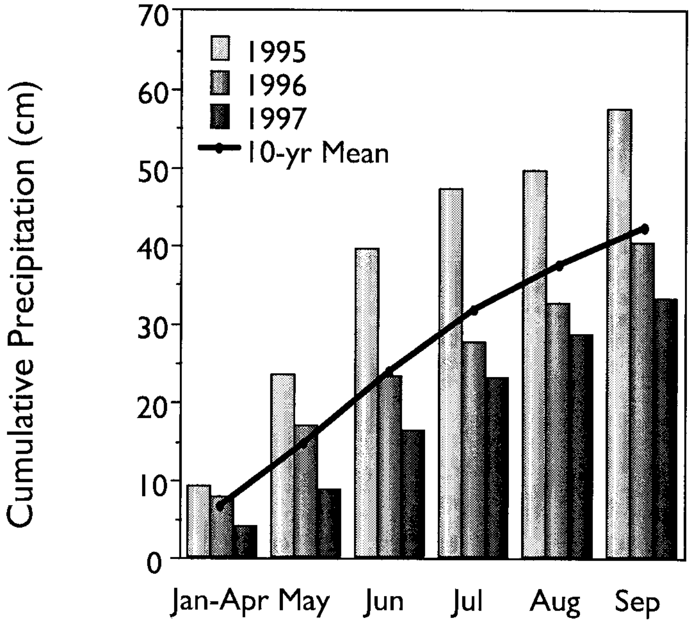

Fig. 1. Cumulative precipitation during 1995, 1996, and 1997 at the Gudmundsen Sandhills Laboratory, near Whitman, Nebr.

between VO and current-year herbage in the autumn was examined in a concurrent study in the same pastures. The relatively small amount of variation in autumn cover among pastures accounted for by current-year herbage during 1995 to 1997 (Volesky et al. 1999) further supported the conclusion that carryover herbage has a measurable effect on autumn cover.

Grazing Pressure

Three levels of stocking rate and measurable differences in palatable herbage among pastures and years resulted in a wide range of grazing pressure within each month (Fig. 2). Mean yields of palatable, current-year herbage immediately before application of grazing treatments were 787, 582, and 645 kg ha^{-1} in May and 1,364, 1,347, and 863 kg ha^{-1} in July during 1995, 1996, and 1997, respectively. Grazing pressure accounted for about twice as much of the variation in autumn cover among pastures after July grazing (R^2 = 0.62) compared to June grazing (R^2 = 0.34). Rapid plant growth from mid-June to mid-July offset the effects of relatively heavy grazing pressure on standing herbage over a wide range in species composition (Cullan et al. 1999). Visual obstruction declined by 1 cm for each 23 AUD Mg^{-1} increase in cumulative grazing pressure in June. In contrast, VO after grazing in July declined about 1 cm for each 9 AUD Mg^{-1} increase in cumulative grazing pressure up to 40 AUD Mg^{-1} after which little change occurred. This concurs with an exponential decline in cover as summer stocking rates increased during June to September on mixed prairie in North Dakota (Duebbert et al. 1986).

Our results indicate that the amount of standing herbage remaining after grazing Sandhills pastures in July is a critical factor in determining the quality of cover for wildlife after killing frost. Distribution and architecture of carryover herbage and differences in plant density may be important factors when selecting pastures to provide adequate cover on a percentage of the landscape. The likelihood of livestock consuming carryover herbage during the summer increases as grazing pressure increases and as plants mature. If all palatable current-year herbage was readily available to livestock, 50% use would occur between 61 and 42 AUD Mg^{-1} if daily dry matter intake ranged from 1.8 to 2.6% of body weight, respectively. However, a percentage of the current-year herbage is frequently obscured by carryover herbage with relatively low nutritive value. Differences in nutritive value of carryover and current-year herbage decline as plants mature. Numerous field observations during October and November at the Gudmundsen Sandhills Laboratory indicate that dormant-season herbivory primarily affects leaf tissue leaving a relatively high percentage of elongated tillers, regardless of age. Average height of visual obstruction will decline with dormant-season grazing even though the maximum height of herbage may not change. Architecture of the remaining herbage in winter-grazed pastures may play a complementary role in providing adequate levels of cover in the autumn following summer grazing.

The habitat suitability index proposed for sharp-tailed grouse (Prose 1987) assigns a nesting cover value of 0 when average visual obstruction is $\leq$ 5.0 cm because successful nests have not been observed with less cover. End-of-season visual obstruction for individual pastures was above 5 cm regardless of stocking rate or date of grazing in our study (Fig. 2). However, sharp-tailed grouse populations are at risk in areas with minimal cover because of relatively low levels of nesting success and the potential for snow induced reductions in cover before nest sites are selected in the spring (Prose 1987).

Wildlife biologists have selected a minimum visual obstruction value of 6.9 cm for sustaining grouse populations at the Samuel R. McKelvie National Forest, 60 km northeast of the Gudmundsen Sandhills Laboratory. High levels of cumulative grazing pressure in June resulted in nearly complete use of palatable current-year herbage within the physical limits of livestock herbivory. Plant growth after mid-June provided enough cover to meet this standard after light, moderate, or heavy stocking, 16, 32, or 48 AUD ha^{-1}, except in 2 cases in 1997 when precipitation was 13% below average. In contrast, end-of-season visual obstruction after moderate stocking in July was $\geq$ 6.9 cm only in 1995 when annual precipitation was 34% above average (Fig. 2).

Repeated heavy use of prairie sandreed during June or July or repeated heavy use of sand bluestem in July in conjunction with below average precipitation will cause measurable reductions in total organic reserves (Reece et al. 1996). Cattle selectively graze prairie sandreed removing about 50% of its herbage at cumulative grazing pressures of about 28 AUD Mg^{-1} and 60% at 40 AUD Mg^{-1} (Cullan et al. 1999). Deferring grazing to August or later, the year after June grazing would enhance prairie sandreed vigor and avoid jeopardizing nesting success of grassland bird species (Jensen et al. 1990, Paine et al. 1996) because of removal of cover and trampling of nests.

Frequency of low-cover patches (VO $\leq$ 5 cm) with nesting cover values of 0 and average visual obstruction in pastures were highly correlated (R^2 = .94) indicating that the quality of cover near potential nesting sites also declined as the average height of visual obstruction declined in

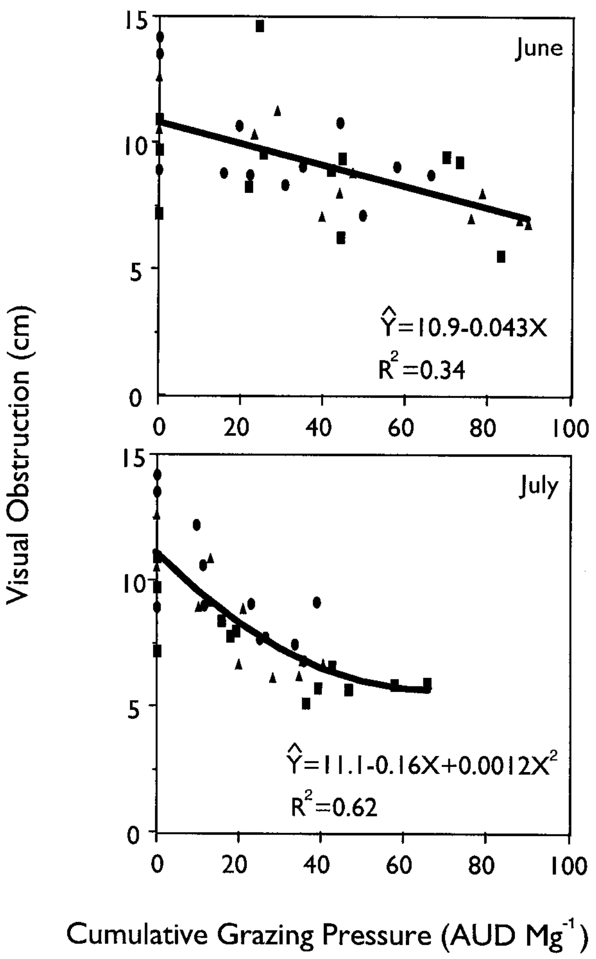

Fig. 2. Effects of cumulative grazing pressure in mid-June or mid-July on visual obstruction (n = 36) at the end of growing seasons during 1995 (n), 1996 (▲), and 1997 (■) on sands range sites in good to excellent condition at the Gudmundsen Sandhills Laboratory near Whitman, Nebr.

pastures, regardless of grazing date (Fig. 3). During a 3-year period, frequency of low-cover patches declined by about 10 percentage points for each 1-cm increase in visual obstruction from 63% at 5 cm to 12% at 10 cm, approaching 0% after 12 cm regardless of grazing treatments (Fig. 3). About 38% of sample areas were low-cover patches when average visual obstruction in pastures was at the standard of 6.9 cm. The interdependence of low-cover patches and mean visual obstruction in our study indicates that either one of these habitat characteristics could be the primary criterion for nest site selection up to 12 cm in VO.

Multivariate Effects

Collectively, grazing pressure, precipitation, and/or frequency of occurrence of plant species accounted for 46% of the variance in autumn cover among June-grazed pastures and 81% when pastures were grazed in July (Table 1). Precipitation and frequency of occurrence of plant species accounted for 59% of the variance in autumn cover among ungrazed pastures. The contrast in predictability after grazing in June compared to July corresponds to only a 30-day difference in time from the end of grazing to killing frost. The relatively high diversity of plant species in these pastures (Northup 1993) and the potential for many species to grow rapidly from mid-June to mid-July (Hendrickson et al. 1997, Reece et al. 1999) may have contributed to the greater variability in autumn cover after grazing in June compared to July.

Precipitation

While annual precipitation ranged from 87 to 134% of the 10-year average, most of the differences in precipitation among years occurred during May and June (Fig. 1). Differences in cumulative precipitation among years were relatively small at the end of April. Precipitation during May was about 14 cm in 1995, 9 cm in 1996, and 5 cm in 1997. June precipitation was about 16 cm in 1995 compared to 7 cm in 1996 and 1997. However, only May precipitation was selected from all possible single and multiple month combinations (Table 1).

May precipitation accounted for 32% of the variation in cover among ungrazed control pastures and 11% of the variation among July-grazed pastures during 3 years. In contrast, precipitation had no measurable effect on autumn cover when pastures

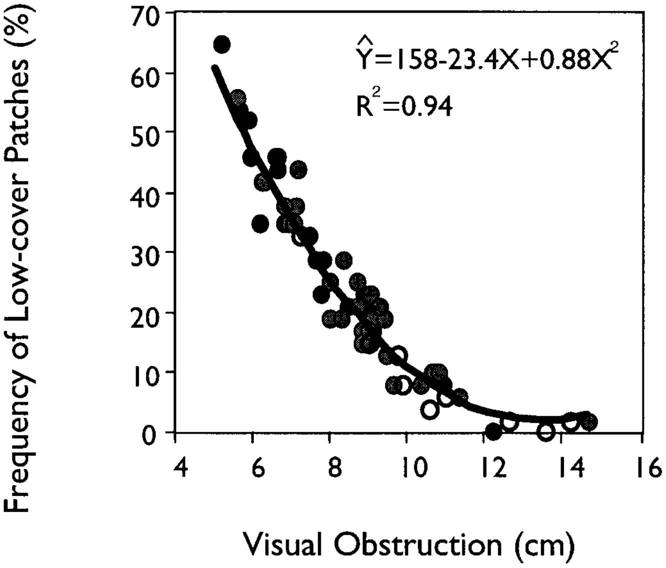

Fig. 3. Relationship between the frequency of low-cover patches with visual obstruction ≤ 5 cm and mean visual obstruction for 1.0-ha pastures (n = 63) after killing frost in September for June-grazed (n), July-grazed (n), and ungrazed control (❍) pastures at the Gudmundsen Sandhills Laboratory near Whitman, Nebr., during 1995 to 1997.

were grazed in June. During previous grazing studies in the same pastures, the percentage of current-year palatable herbage composed of cool-season species in mid-June ranged from 9 to 20% (Northup 1993). Moderate to heavy use of cool-season species in mid-June may have increased the availability of soil moisture and nutrients to warm-season plant species.

Plant Species

Frequency of occurrence of hairy grama in 0.01-m^2 quadrats was associated with 27% of the variation in cover among control pastures during 3 years (Table 1). The positive relationship between a short-grass species and visual obstruction in this study was related to the positive correlation ($P < 0.001$) between the occurrence of hairy grama and 2 tallgrass species, prairie sandreed ($r^2 = 0.41$) and sand bluestem ($r^2 = 0.50$). In the absence of grazing, differences in cover associated with plant communities were similar to those associated with precipitation differences among years (Table 1).

Table 1. Variables and partial R^2 values for multiple regression equations for autumn visual obstruction in ungrazed control, June-grazed, and July-grazed pastures based on stepwise selection from cumulative grazing pressure, precipitation during individual and multiple months of each year and frequency of occurrence of selected grass species.

Dependent Variables[1]	Control	June	July
	(partial R^2)		
Grazing pressure (G)	—	.29	.66
May precipitation (M)	.32	—	.11
Hairy grama (H)	.27	—	—
Little bluestem (L)	—	.17	—
Prairie sandreed (P)	—	—	.04
		.59	46.81

Control $Y = 6.0 + 0.3\ M + 0.0089\ H^2$

June $Y = 9.6 - 0.039\ G + 0.001\ L^2$

July $Y = 6.8 - 0.27\ G + 0.0028\ G^2 + 0.0077\ M^2 + 0.00057\ P^2$

[1]Variables were selected at $(P > F) \leq 0.05$ for June and July grazing treatments (n = 27) and at $(P > F) \leq 0.10$ for control (n = 9). Frequencies of occurrence selected for regression models were derived from nested quadrat areas of 0.01 m^2 for hairy grama, 0.05 m^2 for little bluestem and 0.25 m^2 for prairie sandreed.

In June-grazed pastures, the frequency of occurrence of little bluestem in 0.05-m^2 quadrats was associated with 17% of the variation in autumn cover among pastures during 3 years (Table 1). Increases in visual obstruction related to increases in little bluestem may be directly related to the foliar architecture of this species. This warm-season bunchgrass is characterized by the accumulation of relatively high densities of 30 to 50 cm tall reproductive culms from past years. Carryover of several residual reproductive culms in a bunch causes measurable reductions in the use of current-year little bluestem herbage by cattle (Brummer 1994).

Vegetation had the least effect on cover in July-grazed pastures with the frequency of occurrence of prairie sandreed associated with only 4% of the variation in mean visual obstruction among pastures compared to 66% of the variation accounted for by grazing pressure (Table 1). Prairie sandreed is a rhizomatous tallgrass characterized by populations of dispersed tillers and a relatively low frequency of reproductive culms per unit area compared to mid and tall bunchgrasses (Weaver 1965). However, when precipitation was 134% of average in 1995, density of prairie sandreed tillers increased as cumulative grazing pressure increased in July-grazed pastures compared to ungrazed control pastures (Cullan et al. 1999). Increases in tiller densities that occurred in 1995 were not sustained in the following year when precipitation was near average. Increases in cover that corresponded to occurrence of prairie sandreed may also be related to other plant species because high frequencies of occurrence of prairie sandreed are associated with high seral stages characterized by a greater abundance of mid and tallgrass species with the potential to contribute directly to visual obstruction.

Mean frequencies of occurrence for pastures ranged from 10 to 20% for hairy grama, 18 to 48% for little bluestem, and from 86 to 98% for prairie sandreed. Based on multivariate regression equations, variables associated with differences in the distribution of plant species among pastures could change end-of-season visual obstruction values by 2.7 cm in ungrazed pastures, 2.0 cm in June-grazed pastures, and 1.3 cm in July-grazed pastures. Additionally, the quadratic relationship between visual obstruction and frequency of occurrence for all 3 species (Table 1) indicated relatively small differences in the distribution of plant species accounted for measurable differences in the ability of pastures to produce cover under the same grazing treatment.

Autumn cover was unexpectedly high in ungrazed control pastures after a 30% reduction in annual precipitation during the second year. Given the concurrent and uniformly spaced declines in May precipitation, selected in multivariate regression analysis, and uniformly spaced declines in autumn cover on ungrazed control pastures, precipitation in this study may have been confounded with the progressive decline in carryover herbage that accumulated during 2 years of rest before this study was initiated. Additionally, the concurrent lack of precipitation effects and relatively high amount of variation in autumn cover among June-grazed pastures accounted for by the frequency of occurrence of little bluestem may have been linked to this confounded relationship. Accumulation and duration of carryover herbage are often greater for little bluestem than any other species in the Sandhills (Brummer 1994). Selection of different plant species for each grazing treatment in multivariate analysis, the inability of hairy grama to directly affect cover, and the potential confounding of little bluestem with carryover herbage, indicate a need for caution when using frequency of occurrence of plant species to predict autumn cover. Future research on "indicator" plant species for wildlife cover should include pastures with a wide range in average carryover herbage at the beginning of the study and annual quantification of carryover herbage.

Results of our study are most applicable where limited variation in landscape or relatively high stocking densities result in uniform distribution of grazing. Best management practices for wildlife habitat and plant vigor should be integrated to enhance herbage production and accomplish resource management objectives. About 90% of the visual obstruction values for June-grazed pastures met or exceeded the minimum cover standard (6.9 cm) for sustaining sharp-tailed grouse populations in this area, regardless of stocking rate. In contrast, only light stocking rates consistently produced acceptable levels of autumn cover after grazing in July. Light to moderate stocking rates in June or July and changing the date of grazing by 60 days or more the year after early summer grazing may be necessary to reduce the risk of low vigor in prairie sandreed and sand bluestem (Reece et al. 1996). Increased amounts of residual standing herbage from periodic years of rest may allow pastures to be grazed at moderate stocking rates in July when annual precipitation is average or below average and still provide adequate levels of nesting cover the following spring. Additionally, periodically providing full growing season deferment and grazing only during the dormant season will enhance vigor in prairie sandreed and sand bluestem (Reece et al. 1996).

Managing grazing for sharp-tailed grouse nesting cover in all pastures would require a measurable reduction in stocking rates traditionally used in range livestock enterprises, however, it may not be necessary to provide cover over the entire landscape. Sharp-tailed grouse populations can be sustained when high quality cover is well distributed within their home range of 10 to 50 km^2 to optimize the carryover of adults needed to sustain populations (Sisson 1976). In the absence of livestock, weathering during the dormant season, may lower visual obstruction below levels considered adequate for sustaining wildlife populations. Given the lack of predictability of weather related losses in cover from autumn to spring, the relative value of increasing autumn cover standards to reduce the intermittent risk of inadequate nesting cover in early spring, should be weighed against the effects of consistently lower stocking rates on livestock enterprises.

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Sequential sampling protocol for monitoring pasture utilization using stubble height criteria

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Abstract

Stubble height, a measure of the amount of vegetation remaining after grazing, is thought to be a useful variable in the management of riparian areas. A number of riparian and grazing processes appear to be directly or indirectly affected by the residual stubble height. Thus, average stubble height is often used to evaluate the livestock impact a pasture has received, particularly in riparian zones. Stubble height sampling methodology has received little previous attention. A sequential sampling procedure for stubble height was investigated. The procedure provides statistically defensible answers in the shortest possible amount of time. The procedure does not require a rigid sample size and involves simple yes/no answers at each observation. A small initial sample of readings is selected and evaluated. If there is sufficient information to make a clear decision, then grazing is either continued or stopped. If the initial evidence does not clearly support either decision, then sampling proceeds. This may continue for several iterations before a decision is reached. Statistically supportable decisions can typically be made within a short time frame using this method. This method may also be applied to evaluate trampling and other yes/no responses.

Resumen

Se piensa que la altura del restrojo, una media de la cantidad de vegetación remanente después del apacentamiento, es una variable útil en el manejo de áreas ribereñas. Un número de procesos ribereños y de apacentamiento parecen ser afectados directa o indirectamente por la altura del restrojo remanente. Así, el promedio de la altura del restrojo a menudo es utilizado para evaluar el impacto del ganado en el potrero, particularmente en zonas ribereñas. La metodología de muestreo de la altura del rastrojo ha recibido poca atención. Se investigo un procedimiento de muestreo secuencial para la altura del restrojo. El procedimiento provee respuestas estadísticamente defendibles en el mas corta cantidad de tiempo posible. El procedimiento no requiere de un tamaño de muestra rígido e involucra respuestas simples de si/no para cada observación. Una pequeña muestra inicial de lecturas es seleccionada y evaluada. Si hay suficiente información para tomar una decisión clara, entonces el apacentamiento es continuado o detenido. Si la evidencia inicial no soporta claramente cualquiera de las decisiones entonces se procede a muestrear. Esto puede continuar para varias repeticiones antes de lograr tomar una decisión. Las decisiones estadísticamente soportables típicamente pueden ser tomadas en un corto tiempo utilizando este método. Este método también puede ser aplicado para evaluar el pisoteo y otras respuestas de si/no.

Key Words: grazing management, riparian areas

Stubble height criteria are often applied as guides in the grazing management of riparian areas (USDA-FS 1993, 1994, Hall and Bryant 1995, Leonard et al. 1997, Mosley et al. 1997, Oregon State University 1998, USDA-NRCS 1999). This measure of the herbaceous vegetation remaining after grazing is most appropriately used as a short-term guide applied to attain long-term ecological objectives. Experienced observation and limited research have suggested that a number of riparian processes and characteristics can benefit, directly or indirectly, when a minimum amount of stubble height remains after grazing (Clary and Leininger 200x). Other than in mountain meadows, the use of stubble height has not been directly tested in many riparian sites and, indeed, there have been indications that other management criteria may be more effective in some situations.

When stubble height is used to make management decisions, it is important that those decisions are based upon reliable data. It is easier to sample stubble heights than some other attributes, however, accurate sampling of stubble height is not as simple as it may first appear. Although stubble heights can be quite uniform, as with most variables in nature, substantial variation is often present within the sampling domain. Vegetation within some locations in a pasture may be much shorter than a target height or standard while other locations may be much taller, making it difficult to decide whether the average stubble height over the entire pasture is shorter or taller than a given standard. This complicates the decision whether or not to continue grazing. Another complication in many pastures is the presence of several distinctly different strata. For example, 5 cm may be a reasonable stubble height in stands of bluegrass, but 15 cm may be more appropriate for streamside sedge communities or wet portions of the pasture. The management criteria may be to stop grazing when 50% or more of the possible plots in the drier portion of the pasture are utilized to an average stubble height of 5 cm or less, or if 50% or more of the possible streamside sedge plots are grazed to a stubble height of 15 cm or less.

Although Canfield (1942) proposed a shortcut method for estimating grazing use, his procedure lacks statistical rigor and it may not be applicable beyond the southwest area in which it was developed. Instead, perhaps the classical method for answering

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such questions is to determine utilization for a predetermined number of randomly sampled plots and use the sample information to make inferences about the entire population, which is the pasture. If the proportion of plots utilized in the random sample is “much” less than the standard, grazing is allowed to continue. If the proportion of plots utilized in the sample is "much" more than the standard, then grazing is stopped. A rigorous definition of “much more” and "much less" may be developed using statistical hypothesis tests with a discussion of sample sizes necessary to obtain specified type I and II error rates. Introductory statistical methods texts such as Ostle and Mensing (1975) or Moore and McCabe (1989) provide thorough coverage of classical statistical testing.

An alternative to classical testing methods is to take repeated small samples until enough evidence for a decision is accumulated. This process is known as sequential sampling, and is the focus of this paper. Mood et al. (1974) or Ostle and Mensing (1975) provide readable methodological background and development material.

Sequential Sampling

Sequential sampling starts by selecting a series of relatively small samples and evaluating the cumulative evidence after each sample. At each evaluation, 1 of 3 decisions is made: continue grazing if the data show “clearly” that the stubble height utilization percentage is less than the target; stop grazing if the data show “clearly” that the stubble height utilization percentage exceeds the target; or take another sample if the data are indeterminate. “Clearly” is used to indicate that enough information has accumulated to allow a definitive conclusion for a statistical test. When 40 to 50% of the *population* of plots have been grazed to an average stubble height lower than some target value, grazing should stop. However, the difficulty comes in trying to decide when this stage has been reached based on a relatively small *sample* of plots. Sequential sampling provides 1 method of resolving this difficulty.

Although actual measurements could be made at each sampling location and a running mean and standard error computed after each sample, this is more precision than required for our purposes. Instead, we classify a sampled plot as utilized or not (yes/no). The running proportion of utilized plots is then used to make inferences about the utilization level of the entire pasture.

We define a plot as *utilized* if the average stubble height in the plot is equivalent to or shorter than a specified target value. For example, if a manager feels that it is time to stop grazing when the average stubble height over the pasture is 5 cm or less, then 5 cm would be the target value. An individual plot would be utilized if the average stubble height over the plot is less than 5 cm. If the entire pasture were divided into uniform sized plots, it would be defined as *fully utilized* if the proportion of utilized plots (denoted π) exceeded some specified target value. For example, if more than 50% of all plots are utilized, then the entire pasture is defined as utilized.

Four values must be specified to define a sequential sampling procedure. First is a target value defined as the optimum or desired percent utilization. Without loss of generality, if 40% or less of a pasture is utilized, then it is generally safe to allow grazing to continue. This 40% would be the value specified in the classical null hypothesis of statistical testing using a random sample, i.e., H_o: Utilization proportion (π_o) $\leq$ 0.40. The target utilization proportion (0.40 or 40% here) is in general denoted π_o and the null hypothesis is written in general terms as $H_o: \pi \leq \pi_o$.

The second value is an alternative proportion. In classical hypothesis testing, this is the opposite of the null hypothesis, i.e., H_a: Utilization proportion (π) $\geq$ 0.40 or $H_a: \pi \geq 0.40$. In sequential sampling, we instead specify an upper limit. For example, if 40% is the target value, it may be reasonable to allow grazing to continue even if the sample utilization proportion reaches 50%. Sequential sampling tests the null hypothesis $H_o: \pi = 0.40$ against the alternative hypothesis $H_a: \pi = 0.50$. Note that for all practical purposes, the null and alternate hypotheses may be written as before to include ranges of values, i.e., $H_o: \pi \leq 0.40$ and $H_a: \pi \geq 0.50$. The alternate utilization proportion (0.50 or 50% here) is in general denoted π_a. The indeterminate region between 0.40 and 0.50 where neither hypothesis is supported may be viewed as a "warning" area, i.e., since utilization will increase as long as the animals are present, time on the pasture is growing short.

Types of Errors

Before testing, we must discuss the kinds of errors that can be made. Since one or a series of samples are being used to make inferences about the entire population or pasture, any decision made could be incorrect. If we reject the null hypothesis by concluding that the utilization proportion is greater than 40%, *a type I error* would be made if the true (but unknown to us) utilization proportion over the entire pasture was in fact less than 40%. The consequence of this type of error is that the animals would be moved too early. From a resource manager’s point of view, this is a conservative approach which helps to insure protection of the resource. The type I error rate is denoted by α and values of 0.05 and 0.10 are common (Moore and McCabe 1989).

The flip side is a *type II error*, denoted by β, which can occur only if we fail to reject the null hypothesis when it is false, i.e., we fail to reject $H_o: \pi \leq 0.40$ when in fact the utilization proportion is really 50% or more. This is a serious kind of error with a potentially severe consequence: grazing would continue longer than it should, possibly degrading or damaging the resource.

In classical hypothesis testing, type II error rates are difficult to control because they require the true underlying utilization proportion to be known. Since this is seldom the case, type II error rates are typically computed for a range of true underlying values. However, in sequential sampling, we are technically trying to decide which of 2 values is correct, the value in the null hypothesis or the value in the alternative, and so "truth" is considerably simplified. Consequently, the type II error rate can and, in fact, must be specified in order to define the sequential sampling procedure. Type II error rates of 0.05 and 0.10 are often used (Moore and McCabe 1989).

Sequential Sampling Rules

Given the 4 values, π_o, π_a, α, and β, in combination with a cumulative sample of *n* plots, threshold values of X_c and X_s are calculated to respectively indicate when grazing is to continue or stop. Grazing will continue if the number utilized in the current sample of *n* is less than or equal to X_c, defined as $-h_1 + sn$. Similarly, grazing will stop if the number of utilized plots in the current sample of *n* is less than or equal to X_s, defined as $h_2 + sn$. If the number utilized in the sample is between X_c and X_s, then the sample evidence is inconclusive and more observations must be taken. The constants h_1 , h_2, and *s* are computed as

$$h_1 = \left(\log((1-\alpha)/\beta)\right)/k \quad (1)$$

$$h_2 = \left(\log((1-\beta)/\alpha)\right)/k \quad (2)$$

$$k = \log\left(\frac{\pi_a(1-\pi_o)}{\pi_o(1-\pi_a)}\right) \quad (3)$$

$$s = \left(\log(1-\pi_o)/(1-\pi_a)\right)/k \quad (4)$$

As a practical matter, the smallest X_c can be (and by extension n) to make a decision to continue grazing is the integer just larger than h_1/s. Similarly, the smallest X_s can be to make a decision to stop grazing is the integer just larger than $-h_2/(s-1)$. Both X_c and X_s should be rounded up to the next largest integer and the largest of these 2 values taken as the minimum sample size. Succeeding sample sizes are chosen for convenience and can be as small as one. However, successive sample sizes are probably better if chosen closer to the initial sample size (e.g., add additional transects rather than individual plots).

The values X_c and X_s give a rigorous definition of "clearly" mentioned above. If the number of utilized plots in the sample is less than or equal to X_c, then the evidence is clear that the pasture is not yet utilized to the prescribed level. When the number of utilized plots in the sample is greater than or equal to X_s, then the evidence is clear that the pasture is utilized to at least the prescribed level and grazing should stop. If the number of utilized plots in the sample is between X_c and X_s, then the sample evidence is inconclusive and further sampling must be done.

Simulation Results

Figure 1 depicts results from 1,000 simulations at each of 5 values of the true underlying utilization proportion (labeled π_{true}). The minimum, maximum, and average total number of observations to make a decision for a sampling plan with type I and II errors both set to 0.05 and the target and alternative utilization proportions set to 0.40 and 0.50, respectively, are illustrated. Note that for true utilization proportions between the target and alternative proportions, the maximum sample size can get very large. In practice, if the evidence is not "clear" or conclusive after the cumulative sample size exceeds 100, it is generally safe to conclude that the underlying proportion is likely close to or between the target and alternative values and so preparations should begin to halt grazing.

Example

Using the above values, $\pi_o = 0.40$, $\pi_a = 0.50$, $\alpha = 0.05$, and ß = 0.05, k and s are 0.4055 and 0.4497, respectively, making h_1 and h_2 both equal 7.26. This makes the minimum sample size for continuing and stopping grazing 17 and 14, respectively, hence the initial sample should be 17 observations.

If a transect covering the pasture is about 400 paces, a sampling fraction of 400/17 = 23.5 may be computed, meaning that a utilization plot should be classified every 23rd pace after a random start. For example, if 12 were the random number selected from 1 through 23, sampling would occur at the 12th, 35th (12 + 23), 58th (35 + 23), etc. paces along the transect.

For this sample size and these values of π_o, π_a, α, and ß, the continue grazing value (X_c) is $-h_1 + sn = -7.26 + .4497*17 = 0.3849$ which is rounded up to 1. The stop grazing value (X_s) for 17 observations is $h_2 + sn = 7.26 + .4497*17 = 15$. Hence, if 1 or fewer of the 17 sampled plots are classified as utilized after walking the transect, grazing can continue. However, if 15 or more of the 17 sampled plots are classified as utilized, grazing should stop. Otherwise further data should be collected. For convenience, 20 plots are taken for each succeeding transect. Figure 2 shows the acceptance/rejection envelope for this plan (an initial sample of 17, succeeding samples depending on the cumulative number of utilized plots). Figure 3 displays the same information as a cumulative percentage. The information in Figures 2 and 3 is also presented in the figures and in the table portion of the spreadsheet in Figure 7. In practice, if more than 5 or 6 transects are needed, i.e., if the cumulative sample size exceeds 100, arrangements should be made to stop grazing soon because the actual utilization is likely greater than the target value and fast approaching the alternative value.

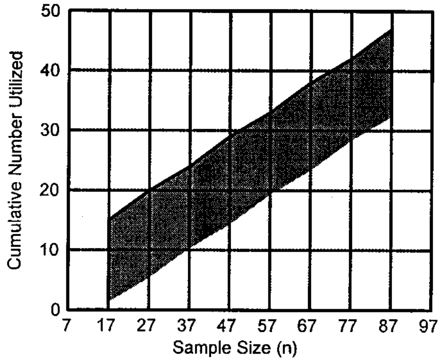

Fig. 2. Sequential sampling plan for $\pi_o = 0.40$, $\pi_a = 0.50$, $\alpha = 0.05$, and $\beta = 0.05$. Stop grazing if cumulative utilization is above the upper band, continue grazing if cumulative number of utilized plots is below the lower band, otherwise continue sampling.

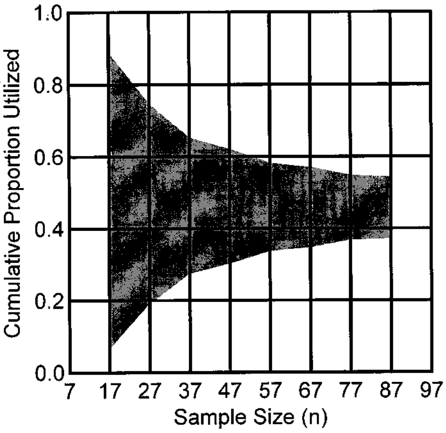

Fig. 3. Sequential sampling plan for $\pi_o = 0.40$, $\pi_a = 0.50$, $\alpha = 0.05$, and $\beta = 0.05$. Stop grazing if cumulative utilization is above the upper band, continue grazing if cumulative % utilized plots is below the lower band, otherwise continue sampling.

Practical Application

Riparian pastures are typically heterogeneous in nature and often serpentine in form. Thus, sampling valley bottoms by random or systematic grid procedures is not very efficient, particularly when sam-

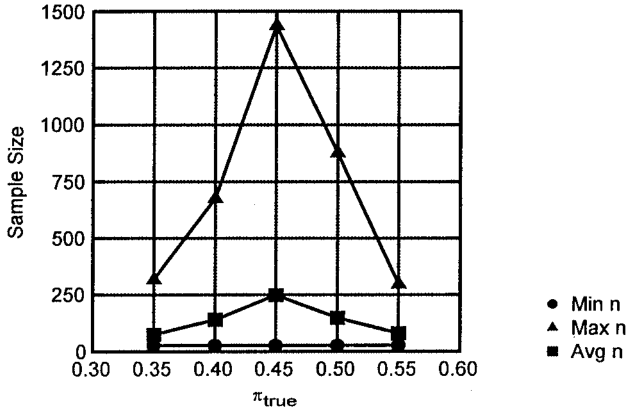

Fig. 1. Simulation results for 1,000 trials with $\pi_o = 0.40$, $\pi_a = 0.50$, $\alpha = 0.05$, and $\beta = 0.05$.

Spreadsheet to define sequential sampling rules

Change the highlighted values to suit your problem

Probability of a type I error (stop grazing too early)	0.05
Probability of a type II error (stop grazing too late)	0.05
Target utilization proportion (continue grazing if utilization) is less than equal to this value)	0.40
Allowable difference from target (Exceeding target utilization) by this % of target or more will cause grazing to stop)	0.25
successive sample size = (if initial sample size produces) inconclusive result)	10

Resulting sequential sampling parameters:

Target%: 40%
Alternative %: 50%
k= 0.4055
s= 0.4497
h1= 7.2619
h2= 7.2619

Smallest sample size to continue grazing:	17
Smallest sample size to stop grazing:	14
Smallest sample size for this setup:	17

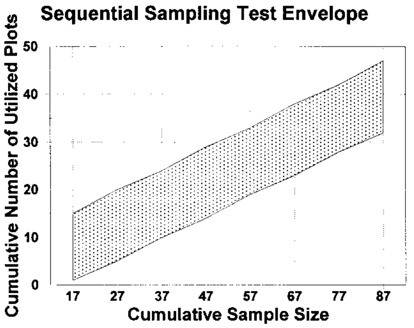

Table 1. Sampling Plan: Continue if cumulative count or percentage is less than or equal, stop if cumulative count or percentage is greater than or equal to table value

Pass Number	Cumulative Sample Size	Cumulative Continue Count	Cumulative Stop Count	Cumulative Continue Proportion	Cumulative Stop Proportion
1	17	1	15	0.059	0.882
2	27	5	20	0.185	0.741
3	37	10	24	0.270	0.649
4	47	14	29	0.298	0.617
5	57	19	33	0.333	0.579
6	67	23	38	0.343	0.567
7	77	28	42	0.364	0.545
8	87	32	47	0.368	0.540

If a ninth pass is needed, arrangements should be made to stop grazing soon because the target and the alternative values are very close.

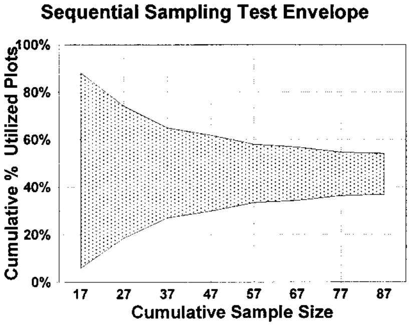

Fig. 4. Spreadsheet example for computing a sampling plan.

pling for characteristics applicable to specific strata such as streamside or drier portions. Under current management approaches, typical stubble height criteria might be a 5 cm height on the dry portion of a valley, and/or a 10 cm height on the wet-meadow or streamside portion of the same valley. Regardless of whether a single criterion or both are used, a typical riparian area would have to be stratified into at least two strata, a comparatively narrow and sinuous streamside or wet meadow strata and the remainder. A decision to stop grazing in either strata would stop grazing in the entire pasture unless grazing in the unstopped strata could continue while stopping in the other strata.

In some cases, the stream is straight enough and the wet-meadow area wide enough that a straight pace transect can be used to sample this strata. Often sampling is best conducted as a "wandering" transect changing direction as necessary to follow the approximate orientation of the long axis of the stratum. The general procedure would be to estimate the total length of the stratum one wishes to sample. A simple spreadsheet (Fig. 4) can be used to determine the minimum sample size and continue/stop criteria for specific π_o, π_a, α, and β values. The sampler would use this minimum or larger number for the initial sample. For example, if the stratum is approximately 300 paces long and the minimum sample size is 20, then a sample plot would be classified every 15 paces. If the first transect does not provide a definitive answer, additional transects are taken until a conclusion is reached or until the sample size exceeds approximately 100 points (5 or 6 transects). If no conclusion is reached after a sample size of that magnitude, it is generally safe to conclude that the true population utilization is close to a decision point and planning to stop-grazing in the near future is justified.

The transects or portions of transects would be sampled by picking a distant landmark and pacing without regard to the specific ground conditions to the next measurement point, in this example, every 15 paces. If necessary, the transect would change direction when the stratum changed direction to maintain the orientation with the long axis of the stratum. If additional transects are needed to arrive at a conclusion, they would also be oriented to the long axis of the stratum and, therefore, would approximately parallel the original transect.

We found that 1.25 m poles, cut from clothes hanger rods with a wrist loop attached and used as walking sticks, were useful in determining whether a plot was utilized. Using this pole with plastic tape bands to mark the height standards, one could read most plots by merely slowing one's pace (see Figs. 5 and 6). Additional useful equipment includes hand-held tally meters. These are used to keep track of total plots evaluated and the number of plots utilized. Using both the reference walking stick and the tally meters, a statistically meaningful survey can be rapidly completed and a scientifically defensible decision made.

Fig. 5. Walking stick/tally pole with tape indicating utilization. This plot would be classified as not utilized.

Fig. 6. Walking stick/tally pole with tape indicating utilization. This plot would be classified as utilized even though there is some vegetation above the tape mark.

Field Trial

Methods and Materials

Field trials were conducted using a pole with 2 bands of tape at 5 and 15 cm from the bottom. A pasture in the Stanley Basin of central Idaho (Lat 114°W 57'56", Long 44°N 13'46") was stratified into wet and dry areas, and samples were taken in both strata. A circle of radius 15 cm around a pole was used to assess the stubble height at each sampled location (plots need to be small enough so that it is visually obvious whether or not they were utilized). Plots were judged to be *utilized* if the average stubble height in a 15 cm radius circle around the pole was shorter than the 5 cm mark in the dry portion of the pasture or the 15 cm mark in the wet area. Figures 5 and 6 show pole placement for plots judged as nonutilized and utilized, respectively. As in the example described above, the probability of type I and II errors was set at $\alpha = 0.05$ and $\beta = 0.10$, respectively. The target and alternative proportions were set at .50 and .60, respectively. Three observers tried the sequential procedure using an initial sample of 13 and successive samples (if needed) of 10.

Results

Figure 7 depicts the sampling stop/continue envelope along with the samples obtained by 3 observers. In the first transect in the dry area, observer 1 found 3 of the 13 or 23% of the samples were utilized. Since this is in the "no decision" or "continue sampling" area of Figure 7, at least 1 more transect must be sampled. The cumulative utilization after the second transect was 9 out of 23 or 39%, still inside the "no decision" area. After the third transect, there were 11 of 33 or 33% utilized, still in the continue sampling region. After the fourth transect, the first observer had accumulated 13 out of 43 or 30% utilization, finally allowing a decision since the cumulative utilization proportion dropped below the continue line in Figure 7.

The second observer had 8% utilization (1 of 13) in the dry area in the first transect which was inside the "no decision" envelope. After the next transect, observer 2 had 8.7% (2 of 23), which moved the

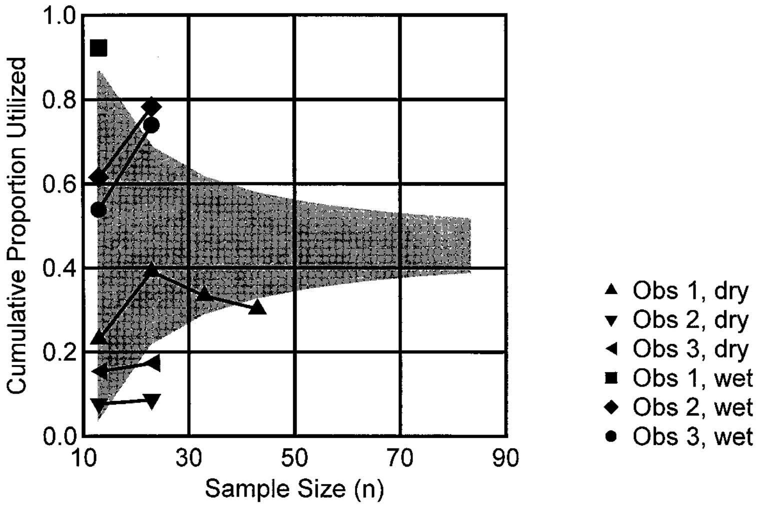

Fig. 7. Wet and dry sampling results for 3 observers. Type I and II errors (α and β) were set to 0.10, target and alternative utilization proportions (π_o, and π_a,) were .40 and .50, respectively. All 3 observers decided to stop grazing in the wet area but allow continued grazing in the dry area based on different length criterion for each area.

cumulative proportion well below the "continue" line in Figure 7 and, therefore, allowed grazing to continue. Observer 3 had a similar experience with 15% utilization (2 of 13) in the first transect and 17% (4 of 23) in the second which also allowed grazing to continue in the dry area.

In the wet area, all 3 observers concluded that grazing should stop. Observer 1 reached that conclusion on the first transect while observers 2 and 3 reached their conclusion on the second transect (Fig. 7). Since it was not possible or practical to fence off the wet area from the dry area at this location, the decision was to stop grazing.

For other scenarios, Figure 4 illustrates a spreadsheet developed to allow easy comparison of sampling plans. Five values must be specified to generate a specific sampling scheme: α and ß the probabilities of type I and II errors (0.05 is a common value); the target utilization proportion πo, (0.40 or 0.50 is usual); the allowable difference from the target as a percentage of the target value (0.20 or 0.25 of π_o, added on to the target value); and successive sample size (usually at least 10%, but 20 or 25% is more realistic) making π_a equal to π_o,(*1 + difference*). A copy of the spreadsheet in Excel format is available at http://www.fs.fed.us/rm/boise or may be requested by sending an e-mail to DLTurner@fs.fed.us.

Conclusion

Many resource managers have used *ad hoc* sampling methods to decide when a pasture has been utilized to a particular stubble height standard. This paper outlined a theoretically sound method of sequential sampling for making accurate and objective determinations of whether a grazed area had been utilized to a specified stubble height. Trampling impacts or other such "yes/no" measures may also be evaluated using this technique. With the ease of the sequential method, there is little excuse for not keeping a careful eye on pasture conditions.

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Chain diker effects on seeded grass establishment following disk chaining

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Abstract

Placing basins in rangeland seedbeds to capture rainfall has enhanced seeded grass establishment, but it has not been practical on debris-littered land following rootplowing for brush control. A disk chain tested previously will traverse land littered with debris or shrubs while tilling the soil for seedbed preparation. A chain diker is an implement designed to form 10-cm deep basins with a volume of 3.9 ± 0.9 liters on tilled land. Combining the 2 implements provided tillage, land smoothing and basin formation in the soil with a single pass on debris littered land. Our 4-year study compared established grass densities on disk-chained seedbeds with and without chain diking at 5 locations in west Texas where land was rootplowed for honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) control. At 4 locations seedbeds were aerially seeded with 2 kg ha^{-1} pure live seed (PLS) of WW Spar bluestem (*Bothriochloa ischaemum* (L.) Keng). At 1 location a mixture of 6 grasses, including Spar bluestem, was aerially seeded at 2.8 kg ha^{-1} PLS. Evaluations were based on established grass densities at the end of the first growing season. At 3 locations, a seeding-before-diking treatment was included to simulate seed dropping from a seedbox mounted over the disk-chain's roller. In the Rolling Plains region of northwest Texas (4 sites), when growing-season rainfall was less than 400 mm, chain-diked seedbeds increased grass densities 2.6 times (P = 0.05) compared to non-diked seedbeds. When growing-season rainfall was greater than 500 mm, grass densities on diked seedbeds were similar to non-diked seedbeds. In the Trans-Pecos region of far-west Texas (1 site), where average growing-season rainfall is 337 mm, diked seedbeds produced 33% greater grass densities (P = 0.05) than non-diked seedbeds with rainfall of 552 mm. Densities of kleingrass (*Panicum coloratum* L.) and Spar bluestem were significantly greater in the diked seedbeds compared to non-diked seedbeds, and the other 4 grasses were not significantly influenced by seedbed methods. Grass densities were similar whether seeding after diking or before diking. Since long-term, growing-season rainfall has averaged below 500 mm between 65% to 87% of the time at these locations, our data suggests that it would be advantageous to include chain diking in combination with disk chaining for grass establishment on rootplowed land littered with brush debris.

Resumen

El poner cuencas en la cama de siembra de pastizales para capturar la lluvia aumenta el establecimiento de zacates, pero no ha sido practico en terrenos con gran cantidad de mantillo y basura proveniente del control de arbustos con arado de subsuelo. Una cadena de disco, probada previamente, cruzaría el terreno con los residuos de plantas realizando una labor de labranza para preparar la cama de siembra. La cadena diqueadora. es un implemento diseñado para formar en terrenos labrados cuencas de 10 cm de profundidad de un volumen de 3.9 ± 0.9 liters. La combinación de los dos implementos provee la labranza, el mullido del suelo y la formación de cuencas con un solo paso en el terreno. Nuestro estudio de 4 años comparo la densidad de zacates establecidos en camas de siembra formadas con cadena de discos con y sin el paso de la cadena diqueadora, este estudio se realizó en 5 localidades del oeste de Texas donde se controlo el mezquite (*Prosopis galndulosa* Torr. var. *glandulosa*) mediante arados de subsuelo. En 4 localidades la siembra se realizó con avión a una densidad de 2 kg ha^{-1} de semilla pura viable (SPV) de "WW Spar bluestem" (*Bothriochloa ischaemum* (L.) Keng), en la otra localidad se sembró un mezcla de 6 zacates incluyendo "Spar bluestem", la siembra se realizó con avión a una densidad de 2.8 kg ha^{-1} de SPV. Las evaluaciones se basaron en las densidades de zacates establecidos al final de la primer estación de crecimiento. En 3 localidades se incluyó un tratamiento consistente en la siembra antes del diqueo para simular la caída de semilla de la caja de siembra montada sobre el rodillo de la cadena disqueadora. En la región de Rolling Plains al noroeste de Texas (4 sitios), cuando la lluvia durante la estación de crecimiento fue menos de 400 mm, las densidades de zacates en las camas de siembra con cuencas se incrementó 2.6 veces (P = 0.05) en comparación con las camas de siembra sin cuencas. Cuando la lluvia durante la estación de crecimiento fue mas de 500mm las densidades de zacates fueron similares en las camas de siembra con y sin cuencas. En la región de Trans-Pecos, situada muy al oeste de Texas (1 sitio), donde el promedio de precipitación durante la estación de crecimiento es de 337 mm, la densidad de zacates en las camas de siembra con cuencas fue mayor en 33% (P = 0.05) que las densidades de las camas de siembra sin cuencas con una precipitación de 552 mm. Las densidades de zacate "klein" (*Panicum cloratum* L.) y "Spar bluestem" fueron significativamente mayores en las camas de siembra con cuencas que en las sin cuencas, la densidad de los otras cuatro especies de zacates no fue influenciada significativamente por la preparación de la cama de siembra; las densidades de zacates fueron iguales sembrandolos antes o después de la formación de los diques. Dado que en estas localidades la lluvia durante la estación de crecimiento ha promediado arriba de 500 mm entre el 65 y el 87% de las veces, nuestros datos sugieren que sería ventajoso incluir la cadena de diqueo en combinación con la cadena de discos para el establecimiento de

Mention of a trade name is for identification only and does not imply an endorsement or preference over other products not mentioned.

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zacates en tierras con residuos de arbustos sujetos a control con arado de subsuelo

Key Words: seedbed, rangeland seeding, brush control, honey mesquite, *Prosopis glandulosa*

Alteration of soil surface topography by basin tillage (pitting) favorably changes soil water availability for seed germination on rangeland (McGinnes 1959). Evans and Young (1987) found 343 times more seedlings in 9-cm pits than on smooth soil. Similarly, the utilization of small dikes between rows, also called basin tillage, to trap rainfall for increased dryland row crop production was tested in the 1930s, but lack of adequate equipment and poor weed control delayed its commercial use until recent times (Lyle and Dixon 1977, Jones and Clark 1987). Advantages of basin tillage were the basis for development of the arid land seeder in New Mexico (Abernathy and Herbal 1973), the range improvement machine in Montana (Erickson and Currie 1982), land imprinter in Arizona (Dixon and Simanton 1977), and the Forest Service Hodder Gouger (Lawson 1980). Although innovative, each has been too costly or impractical for extensive range seedings especially on debris-littered rootplowed land. A summary statement in the 1990 Seedbed Ecology Symposium was "the need for novel equipment for range seeding is critical" (Young 1990).

A disk-chain implement developed by Wiedemann and Cross (1982) used an anchor chain modified by the addition of disk blades welded to alternate chain links and swivels at each end of the chain to till the soil as it was pulled diagonally. It was effective in preparing seedbeds on debris-littered land and was energy efficient (Wiedemann and Cross 1987). Seedbeds prepared by disk-chaining increased seeded grass stands by 100% in clay loam soil and 42% in sandy loam soil compared to seedbeds prepared by a smooth chain on land rootplowed for honey mesquite (*Prosopis glandulosa* Torr. var. *glandulosa*) control (Wiedemann and Cross 2000).

A chain diker developed by Bruce Smallacombe in Australia to trap rainfall on fallow wheat land used specially shaped paddles welded to an anchor chain to form about 45,000 diamond-shaped basins per hectare in tilled soil as the chain rotated (Wiedemann and Smallacombe 1989). Each basin was about 10-cm deep with a volume of 3.9 ± 0.9 liter. Force required to pull the modified chain was 0.94 kN m^{-1} of width as determined by Wiedemann and Cross (1994).

Fig. 1. Chain diker attached to rear of the disk chain was designed to form basins in soil tilled by the disk chain during seedbed preparation on land littered with brush debris. The implement is called a disk-chain-diker (Wiedemann and Cross 1994).

Combining the disk chain and the chain diker as a single unit (Fig. 1) resulted in an implement that provided tillage, land smoothing and basin formation in one operation. Additionally, it was designed to traverse brush debris. The combined unit was termed a "disk-chain-diker." Required force to pull the disk-chain-diker was 2.29 ± 0.09 kN per disk blade, and 20% of that force was attributed to the chain diker (Wiedemann and Cross 1994). At 5 km h^{-1} (the recommended rangeland speed), 3.16 kW per blade of power would be required for pulling.

Information is lacking on the chain diker's efficacy for rangeland seeding. The objective of this study was to compare chain-diked seedbeds with non-diked seedbeds by comparing the density of established grass plants following the first growing season after seeding rootplowed land tilled by a disk chain.

Materials and Procedures

Study Sites

Four research sites were located in the Rolling Plains vegetational resource region of northwest Texas. Three were 40 km south of Vernon (33°57' N, 99° 05' W, elevation 367 m) (Waggoner Ranch) and 1 was 15 km southwest of Guthrie (33°33' N, 100°27' W, elevation 535 m) (Pitchfork Ranch). A fifth site was in the Trans-Pecos resource region of far-west Texas, 8 km north of Big Lake (31°16' N, 101°31' W, elevation 816 m) (Weatherby Ranch). Average annual rainfall is 641mm near Vernon, 545 mm at Guthrie, and 472 mm near Big Lake. Rainfall is highly variable, and the mean distribution is bimodal, with a peak in May and another in September. Rainfall during the 4-year study is presented in Table 1. The average frost-free growing season is more than 200 days, extending from March into November. Growing-season rainfall was tabulated for the period April through October, and the long-term average is 471 mm at Vernon, 437 mm at Guthrie, and 374 mm at Big Lake.

All sites had productive soils suitable for grass seeding. Sites were nearly level to gently sloping uplands (0 to 3% slope), and soils were deep, well drained, and slow to moderately permeable. Soils were classified at the Vernon sites as Tillman clay loam (mixed, thermic Typic Paleustolls), at the Guthrie site as Paducah loam (mixed, thermic Typic Haplustalfs), and at Big Lake site as Reagan loam (mixed, super active, thermic Ustic Haplocalcids). Texture was clay loam at Vernon, varied from mostly loam to a sandy loam at Guthrie, and varied from mostly loam to a clay loam at Big Lake. All sites were infested with regrowth honey mesquite varying in height from 1.8 to 3.0 m. Sites had been aerially sprayed, chained, and re-sprayed several times over

Table 1. Annual and monthly rainfall near the Vernon, Guthrie, and Big Lake sites for the specified year.[1] Growing-season rainfall is April through October.

Month	Vernon			Big Lake	Guthrie[2]
	1988	1989	1991	1990	1991
	(mm)				
Jan.	22	26	70	9	-
Feb.	5	79	0	41	-
Mar.	51	11	13	30	-
Apr.	28	6	2	121	0
May	3	122	129	91	73
Jun.	115	112	110	0	163
Jul.	50	13	91	97	8
Aug.	9	88	69	58	207
Sep.	152	145	131	124	29
Oct.	10	18	66	61	76
Nov.	20	0	7	46	-
Dec.	27	6	117	17	-
Total	492	626	805	695	-

[1]Climatological Data, NOAA, Asheville, N.C. 28801 at Lake Kemp near Vernon, Tex., Guthrie Tex., and Cope Ranch near Big Lake, Tex.
[2]At-site measurement during growing season near Guthrie (Pitchfork Ranch).

the past 30 years except the Big Lake site which had only been chained once.

Equipment

Integral mounted rootplows were pulled with large crawler tractors (175 kW or larger) at depths of 30 to 35 cm to sever honey mesquite roots below the bud zone. The disk chain was constructed from 76-mm-diameter anchor chain with 711-mm-diameter, notched, disk blades welded to alternate chain links. Two, 10-blade gangs with swivels on either end were attached in a triangular configuration and held in place by a 508-mm-diameter flexing roller for a center brace 10.8-m wide (Fig. 1). The unit was pulled by a 104 kW or larger crawler tractor.

The chain diker used the same size anchor chain as the disk chain. Two steel plates 280 x 100 x 13 mm were bent slightly (38 mm depth midway along the length) and welded longitudinally on opposite sides of the chain link to form paddles (Fig. 2). Two, 4.9-m-long diking chains with swivels on each end were pinned in series and attached to the rear of the large rolling brace of the disk chain, 32 links in all. All attachments were flexible so the unit could traverse logs and stumps. Additional disk chain and chain diker details plus construction drawings have been previously described (Wiedemann 1990). When chain diking was used as a separate operation, the disk-chain gangs were replaced by a small smooth chain and the roller and diking chain was pulled as a unit. A 58-mm-diameter anchor chain pulled in a U-shape between 2 crawler tractors (104 kW or larger) accomplished the "smooth" chaining operation.

An Air Tractor 502 aircraft with a 582-kW turbine engine (Air Tractor, Inc., Olney, Tex. 76374) and an Ag-Truck aircraft (Cessna Aircraft Co., Wichita, Kans. 67277) were both equipped with Transland spreaders (Transland Inc., Harbor City, Calif. 90710) for aerial seeding. Seeds were metered through a standard gate box on both planes, and special blending with cracked grain was required to meter chaffy seed. Swath widths were 12 m (Ag-Truck) or 15 m (Ag-Tractor), and flight lines were 366- to 732-m long. The Ag-Truck was used at the Big Lake site only.

Treatments and Experimental Design

Rootplowing for honey mesquite control was conducted in winter months. Seedbeds were prepared 1 to 14 days prior to spring seeding. Disk-chained seedbeds with dikes were prepared with a single pass of the disk-chain-diker. Disk-chained seedbeds without dikes were prepared with the diking chain removed from the disk chain. At 3 sites, seeding was conducted between the disk chaining and diking operations. This simulated seed being dropped behind the roller from a seedbox mounted over the roller. At 1 site, a chained seedbed was prepared by 2 passes of the smooth anchor chain pulled in opposite directions. Treatments were installed in 1988 (Year-1, Vernon), 1989 (Year-2, Vernon), 1990 (Year-3, Big Lake), and 1991 (Year-4, Vernon & Guthrie). Plot size varied from 31 x 122 m to 61 x 305 m (width x length). Treatments were replicated 4 times at each site.

In Year-1, disk-chaining+diking, disk-chaining, and smooth-chaining treatments were installed at the Vernon site (clay loam). In Year-2, disk-chained seedbeds with and without diking were installed at

Fig. 2. Paddles on an anchor chain form basins in the soil as the chain rotates; unit is called a chain diker (Wiedemann and Cross 1994).

Table 2. Grass species and seeding rate (pure live seed) at each site.

Year	Site	Grass Species	Rate
			(kg/ha)
1	Vernon	'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng)	2.8
2	Vernon	'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng)	2.3
3	Big Lake	'Haskel' sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.)	1.01
		'Selection 75' kleingrass (*Panicum coloratum* L.)	0.45
		'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng)	0.40
		Green sprangletop (*Leptochloa dubia* (H.B.K.) Nees)	0.38
		Plains bristlegrass (*Setaria macrostachya* H.B.K.)	0.34
		Blue panic (*Panicum antidotale* Retz.)	0.22
		Total	2.80
4	Guthrie	'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng)	2.3
4	Vernon	'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng)	2.1

the Vernon location. In Year-3, disk-chaining+diking, disk chaining, and seeding before the diking operation were installed at the Big Lake site (loam). In Year-4, the same 3 treatments as Year-3 were installed at Vernon (clay loam) and Guthrie (loam).

'WW Spar' old world bluestem (*Bothriochloa ischaemum* (L.) Keng) was seeded at 2.2 kg ha^{-1} pure live seed (PLS) at 4 sites, and it was part of a mixture with 5 other grasses at Big Lake, (Table 2). When Spar was seeded alone, it was blended in a 1 to 3 (seed to grain) mixture of cracked grain to aid in seed metering from an aircraft (Wiedemann and Cross 1990).

Seeding dates were 25 May 1988, 21 April 1989, 26 February 1990, 13 March 1991 (Guthrie), and 13 April 1991 (Vernon). Each swath of the aircraft was perpendicular to all seedbed preparation methods in a block to minimize the effect of any irregularities in the seeding rate during seeding. A randomized-block experimental design was used each year.

Plots were evaluated at the end of the first growing season (November). Established plant densities were determined from 100, 0.1 m^2 quadrat samples per plot. Plant densities of 5 plants m^{-2} or greater were considered to be successful for rangeland seeding (GPAC 1966).

Statistical Analysis

Analysis of variance was used each year to determine effects of seedbed methods on established plant densities (plants m^{-2}). Means were separated by a protected Least Significant Difference method at P=0.05 (SAS System v6.12, SAS Institute, Inc., Cary, N.C. 27511). Standard errors were calculated for all means.

Results and Discussion

Rainfall

The selected sites from west to far-west Texas were intended to provide a growing-season rainfall gradient decreasing from 471 mm to 337 mm. In reality, 1 site received 367 mm, 21% below normal, and all others sites were above 500 mm. This included a site at 64% above normal rainfall. These amounts of rainfall masked the value of collection basins for low-rainfall conditions.

Year-1 Vernon

Established grass densities were influenced by seedbed methods (P = 0.036). Grass densities on disk chained and diked seedbeds were significantly greater (P = 0.05) than those on non-diked disk-chained seedbeds or those on smooth chained seedbeds (Table 3). Rainfall during the growing season at this site was 367 mm, 21% below normal. Diking increased grass densities 2.6 times over non-diked seedbeds when rainfall was below normal, less than 400 mm. Only the grass densities on the diked seedbeds reached or exceeded the successful level (≥ 5 plants m^{-2}).

At a nearby research farm (50 km) the same year, chain diking in a wheat (*Triticum aestivum* L.) production test significantly increased grain production compared to no diking when rainfall was 22% below normal during the growing season. When rainfall in later years was normal (444 mm) to 48% above normal, diking did not improve yields. Diking reduced runoff by 40% over the 3-year period compared to no diking (Wiedemann and Clark 1996). We would anticipate a similar reduction in runoff on tilled rangeland.

Year-2 Vernon

Grass densities on diked seedbeds following disk chaining were not significantly greater (P > 0.10) than those on non-diked seedbeds (Table 3). Rainfall was 504 mm or 9% above normal. Rainfall amounts greater than 100 mm in both May and June increased grass establishment in all plots and nearby commercial seedings. Diking did not enhance grass establishment when growing-season rainfall was above 500 mm, and all stands were at least twice the successful level of 5 plants m^{-2}. Similar results were observed by Wiedemann and Clark (1996).

Year-3 Big Lake

Analysis of variance showed that the established grass densities varied with seedbed preparation (P = 0.038) and grass species (P = 0.001). Diking significantly increased grass densities by 33% when compared to non-diked seedbeds (Table 3). However, grass densities were similar when seeding was conducted after diking or between the disk chaining and diking operations. This indicates that results from seed dropped on the soil surface from a seedbox mounted above the roller before diking would be no different from seed dropped from an aircraft or other device after diking. At this normally low-rainfall area, growing-season rainfall was 552 mm or 64% above normal. Even though rainfall amounts greater than 90 mm in April, May, and July enhanced grass establishment, the improvement due to the basins remained.

Table 3. Effects of seedbed preparation methods on established grass densities ($\bar{x}$ ± SE).

Seedbed Method	Grass density
	(Plants/m^2)
Year-1 Vernon	
Disk-chain+diking	11.0 ± 2.7a[1]
Disk-chain, no diking	4.2 ± 1.0b
Smooth chaining	2.4 ± 0.8b
Year-2 Vernon	
Disk-chain+diking	13.5 ± 1.7a
Disk-chain, no diking	12.2 ± 1.1a
Year-3 Big Lake[2]	
Disk-chain+diking	6.4 ± 1.0a
Disk-chain, no diking	4.8 ± 0.7b
Disk-chain/seed/diking	5.3 ± 0.7ab
Year-4 Guthrie	
Disk-chain+diking	4.7 ± 0.6a
Disk-chain, no diking	4.8 ± 0.6a
Disk-chain/seed/diking	5.4 ± 0.6a
Year-4 Vernon	
Disk-chain+diking	24.5 ± 7.8a
Disk-chain, no diking	26.0 ± 7.1a
Disk-chain/seed/diking	32.4 ± 4.9a

[1]Means in the column within the same site followed by the same letter are not significantly different at the 5% level.
[2]Species' main effect and the significant interaction is discussed in text and Table 4.

Table 4. Influence of grass species and the effect of seedbed preparation methods on seeded grass species at the Big Lake site ($\bar{x} \pm$ SE).

Grass species	Species Means	Seedbeds Diked	Non-diked	Seeded/diked
	----(Plants/m²)----			
Kleingrass	1.6 ± 0.2A[1]	2.2 ± 0.4a[2]	1.1 ± 0.0.3b	1.6 ± 0.1b
Green sprangletop	1.4 ± 0.2A	1.4 ± 0.3a	1.6 ± 0.3a	1.1 ± 0.4a
Spar bluestem	1.0 ± 0.2B	1.6 ± 0.3a	0.7 ± 0.1b	0.9 ± 0.2b
Sideoats grama	0.5 ± 0.1C	0.4 ± 0.1a	0.5 ± 0.1a	0.7 ± 0.1a
Plains bristlegrass	0.5 ± 0.1C	0.4 ± 0.1a	0.5 ± 0.1a	0.5 ± 0.3a
Blue panic	0.5 ± 0.1C	0.4 ± 0.2a	0.4 ± 0.1a	0.5 ± 0.2a

[1]Means within the species' column (main effect) followed by the same uppercase letter are not significantly different at the 5% level.
[2]Means within a row comparing 3 seedbeds (interaction effect) that are followed by the same lowercase letter are not significantly different at the 5% level.

Stand densities of kleingrass and green sprangletop were significantly greater than densities of Spar bluestem which was significantly greater than densities of sideoats grama, plains bristlegrass and blue panic (Table 4). Densities of the top 3 species were at or greater than 1 plant m^{-2}, while densities of the other species were at or below 0.5 plants m^{-2}. Stands of individual grass species were very sparse, but the total stand density of 5.5 plants m^{-2} was considered successful, especially for this region.

The interaction between seedbed methods and grass species was significant (P = 0.004). Mean comparisons of the interaction for the different seedbeds are listed in Table 4. Kleingrass and Spar bluestem densities in the disk-chain-diked seedbed were significantly greater than non-diked or the seeded-before-diking seedbeds. Grass densities were not different among seedbeds for each of the other 4 grasses, green sprangletop, sideoats grama, plains bristlegrass, and blue panic; this caused the significant interaction. Green sprangletop densities, however, were much greater than the other 3 grass densities.

These data indicate that kleingrass and green sprangletop were aggressive in their establishment regardless of the seedbed preparation. Spar bluestem and kleingrass densities were increased 98% and 129%, respectively, by the diked seedbeds compared to non-diked seedbeds. These 3 grasses were far superior in their establishment compared to the other grasses.

Year-4 Guthrie

Grass densities did not differ (P > 0.10) among the 3 seedbed methods, disk chaining with or without diking or seeding before the diking operation (Table 3.). Average grass density was 4.9 plants m^{-2}. Rainfall at the site was 556 mm which was 27% above the average for the area during the growing season. During June and August, rainfall amounts greater than 160 mm greatly influenced the success of this seeding. It appears that the basins do not influence the establishment of grass when rainfall amounts are at this level, and there is good spring rainfall for emergence and growth. All grass stands were near or above the successful level. As in previous plantings, seeding before or after diking did not make a difference.

Year-4 Vernon

Grass densities did not differ (P > 0.10) among the 3 seedbed methods which were the same as those at the Guthrie site (Table 3.). Rainfall during the growing season was 598 mm, 30% above average. Starting in May there were 3 months with rainfall greater than 100 mm and the rest were above 60 mm. This contributed to an outstanding stand of grass, 27.6 plants m^{-2}. Again, diking did not influence stand establishment with this amount of rainfall.

Conclusions and Management Implications

In the Rolling Plains region of northwest Texas (Vernon and Guthrie sites), when growing-season rainfall was below 400 mm, chain-diked seedbeds increased seeded grass densities of Spar bluestem by 2.6 times compared to non-diked seedbeds following disk chaining of rangeland rootplowed for brush control. When growing-season rainfall was greater than 500 mm, grass densities were not improved by diking. Long-term rainfall records at Vernon indicate that 65% of the time rainfall would be less than 500 mm; therefore, it would be advisable to use chain diking during seedbed preparation.

In the Trans-Pecos region of far-west Texas (Big Lake site), where average growing-season rainfall is 337 mm, diked seedbeds had 33% greater grass densities than non-diked seedbeds even though rainfall was 552 mm. Densities of kleingrass and Spar bluestem were positively influenced by diking, while green sprangletop, sideoats grama, plains bristlegrass, and blue panic densities were not influenced by seedbed methods. Since growing-season rainfall has averaged less than 500 mm 87% of the time, it would be advantageous to use diking in the seedbed preparation process.

Seeding before diking did not result in significantly different grass densities than seeding after diking. These data indicate that seed broadcast from a seedbox mounted over the rolling brace and prior to chain diking would result in similar grass stands to seed dispensed aerially or other broadcast methods after chain diking.

Because of the high probability that growing-season rainfall will be less than 500 mm in western Texas, our findings suggest that it would be advisable to use diking as a necessary part of seedbed preparation. Chain diking in combination with disk chaining (disk-chain-diker implement) when preparing seedbeds for grass seeding on rootplowed land littered with brush debris offers enhanced results, energy efficiency, and a single-pass preparation without the need for costly raking (Wiedemann and Cross 1994, 2000).

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Revegetating spotted knapweed infested rangeland in a single entry

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Abstract

Introducing and establishing competitive plants is essential for the successful management of spotted knapweed (*Centaurea maculosa* Lam.) infested rangeland where a desirable understory is absent. Our objective was to determine a herbicide-mix that would maximize grass establishment in spotted knapweed-cheatgrass (*Bromus tectorum* L.) bluegrass (*Poa pratensis* L.) infested rangeland in a single fall application. On 2 sites in Montana, 8 herbicide treatments [none, glyphosate (N-[phosphonomethyl] glycine) at 0.5 kg a.i. ha^{-1}, picloram (4-amino-3,5,6-trichloropicolinic acid, potassium salt) at 0.14 kg a.i. ha^{-1}, picloram at 0.28 kg a.i.ha^{-1}, clopyralid (3,6-dichloro-2-pyrdinecarboxylic acid, monoethanolamine salt) at 0.21 kg a.i. ha^{-1} plus 2,4-D (2,4-dichlorophenoxyacetic acid) at 1.12 kg a.i. ha^{-1}, picloram at 0.14 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, picloram 0.28 kg a.i.ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and clopyralid 0.2 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}] and 3 seeded grass species [‘Luna’ pubescent wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey], bluebunch wheatgrass [*Pseudorogneria spicata* (Pursh.) Löve], and ‘Bozoyski’ Russian wildrye [*Psathyrostachys junceae* (Fisch.) Nevski] were applied in a split-plot design with 4 replications in the late-fall of 1994 and 1995. Spotted knapweed and grass density were measured in 1995, 1996, and 1997, and biomass was measured in 1997 at peak standing crop. Density data were analyzed as a split-split-plot in time, and biomass data were analyzed as a split-plot using analysis of variance. By the end of the study, picloram applied at either 0.14 or 0.28 kg a.i. ha^{-1} in the late-fall consistently yielded lowest spotted knapweed density and biomass. Initially, glyphosate alone lowered spotted knapweed density and increased grass biomass compared to that of the control. However, glyphosate treated plots had more spotted knapweed and less seeded grass established by the end of the study. ‘Luna’ pubescent wheatgrass consistently yielded the high test density and biomass of the seeded grasses. We believe a single-entry revegetation program applying picloram in late-fall combined with a fall-dormant seeding will maximize seedling establishment in spotted knapweed infested rangeland.

Key Words: rehabilitation, weed management, reseeding, seedling establishment

Resumen

La introducción y establecimiento de plantas competitivas es esencial para un manejo exitoso de pastizales infestados con “Spotted knapweed"(*Centaurea maculosa* Lam.) carentes de vegetación herbácea deseable. Nuestro objetivo fue determinar una mezcla de herbicidas que con una sola aplicación en otoño maximizara el establecimiento de zacates en un pastizal infestado con “Spotted knapweed-Cheatgrass”(*Bromus tectorum* L.) y “Bluegrass” (*Poa pratensis* L.). En dos sitios de Montana, a fines de otoño, se aplicaron 8 tratamientos de herbicidas [control (no herbicida), glifosato (N-[fosfonometil] glicine) en dosis de 0.5 kg i.a. ha^{-1}, picloram (sal de potasio , 4-amino-3,5,6 ácido tricloropicolinico) en dosis de 0.14 kg i.a. ha^{-1}, picloram en dosis de 0.28 kg i.a. ha^{-1} clopiralid, (sal monoetanolamina, 3,6 dicloro-2- ácido pirdinecarboxilico) en dosis de 0.21 kg i.a. ha^{-1} mas 2,4-D (2,4-ácido diclorofenoxiacetico) en dosis de 1.12 kg i.a. ha^{-1}, picloram en dosis de 0.14 kg i.a. ha^{-1} mas glifosato en dosis de 0.5 kg i.a. ha^{-1}, picloram en dosis de 0.28 kg i.a. ha^{-1} mas glifosato en dosis de 0.5 kg i.a. ha^{-1} y clopiralid en dosis de 0.2 kg i.a. ha^{-1} mas 2,4-D en dosis de 1.12 kg i.a. ha^{-1} mas glifosato en dosis de 0.5 kg i.a. ha^{-1}] y se sembraron tres especies de zacates “Pubescent wheatgrass” [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey] variedad ‘Luna’, “Bluebunch wheatgrass" [*Pseudorogneria spicata* (Pursh.) Löve], y “Russian wildrye” [*Psathyrostachys junceae* (Fisch.) Nevski] variedad ‘Bozoyski’. Se utilizó un diseño experimental de parcelas divididas con 4 repeticiones. En 1995, 1996 y 1997 se midió la densidad de “Spotted knapweed” y zacates, y en 1997, se midió la biomasa de zacate en la época de mayor producción de forraje en pie. Los datos de densidad se analizaron como parcelas divididas en tiempo y la biomasas se analizó como parcelas divididas utilizando análisis de varianza. Al final del estudio el picloram aplicado en dosis de 0.14 y 0.28 kg i.a. ha^{-1} tuvieron la mas baja densidad y biomasa de "Spotted knapweed". Inicialmente, comparado con el control, el glifosato solo bajo la densidad de “Spotted knapweed” e incremento la biomasa de zacates.sin embargo, al final del estudio, las parcelas tratadas con glifosato tuvieron mas “Spotted knapweed” y menos plantas establecidas de los zacates sembrados. De los zacates sembrados la especie “Pubecent wheatgrass” variedad ‘Luna’, produjó la mayor densidad de plantas y biomasa. Creemos que un programa de revegetación de una sola vez mediante la aplicación de picloram a fines del otoño en combinación con la siembra en otoño maximizará el establecimiento de plántulas de zacates en los pastizales infestados de “Spotted knapweed”.

Spotted knapweed (*Centaurea maculosa* Lam.) is a serious threat to the diversity and productivity of rangeland in the western United States. This deep taprooted weed is native to grassland

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steppes of central Europe and east to central Russia, Caucasia, and western Siberia (Rees et al. 1996). In the United States, spotted knapweed was limited to the San Juan Islands, Wash., until 1920 (Forcella and Harvey 1980). It had spread to 20 counties in the Pacific Northwest by 1960 and to 48 counties by 1980. Between 1980 and the present, the known range of spotted knapweed rapidly increased to include 326 counties in the western United States, including every county in Idaho, Montana, Washington, and Wyoming (Sheley et al. 1998). Spotted knapweed is detrimental to soil and water resources (Lacey et al. 1989), reduces wildlife and livestock habitat (Watson and Renney 1974, Spoon et al. 1983), and lowers species richness (Tyser and Key 1989).

Over the past several decades, spotted knapweed management has focused on controlling weeds, with limited regard to the composition and persistence of the resulting plant community. It has been proposed that sustainable weed management must focus on establishing desired plant communities that maximize temporal and spatial niche occupation (Sheley et al. 1996). On rangeland devoid of competitive desirable species, weed control is often short-term because desirable species are not available to occupy niches opened by weed control procedures (James 1992, Sheley and Jacobs 1997). In these cases, introducing and establishing competitive plants is essential for the successful management of weed infested rangeland and the restoration of desired plant communities. However, revegetation is often not used as a spotted knapweed management strategy because of the high cost and risk of failure.

Failures in revegetation of weed infested rangeland are usually caused by the combination of a number of factors. The most important are insufficient soil moisture and intense weed competition, and their interaction (Velagala et al. 1997). Inadequate weed control or precipitation usually results in seeding failure, and several attempts at revegetation are required to establish desired stands.

Revegetating spotted knapweed infested rangeland is costly because of the number of attempts required for success and the number of entries onto a site needed to maximize the potential for seedling establishment. Typically, revegetation of weed infested rangeland requires multiple entries. In many situations, the site is disced in late-fall to loosen the soil surface and encourage the germination of weed seeds present in the seedbank. A few weeks later, a nonselective herbicide, such as glyphosate (N-[phosphonomethyl] glycine) is applied to control the newly emerging weeds. The combination of discing and herbicide application reduces the weed seedbank and competition the following spring. Soon after the herbicide is applied, fall dormant grasses are seeded, generally using a no-till drill. The following spring, some of the remaining weed seeds and seeded grasses germinate and emerge. With adequate spring precipitation, both weed and grass seedlings survive. If grass seedlings survive until mid-summer, a reduced rate of 2,4-D (2,4-dichlorophenoxyacetic acid) or mowing is usually applied to reduce the weed competition.

Although revegetation with aggressive species has been shown to limit weed reinvasion (Lym et al. 1997, Whitson et al. 1997), managers are reluctant to attempt it because of this multi-attempt, multi-entry approach. Single-entry revegetation strategies that are cost-effective and reliable must be developed before this important weed management strategy is adopted. Our objective was to determine a herbicide or herbicide-mix that would maximize grass establishment in spotted knapweed-cheatgrass (*Bromus tectorum* L.)/bluegrass (*Poa pratensis* L.) infested rangeland in a single fall herbicide and seeding procedure. We hypothesized that picloram (4-amino-3,5,6-trichloropicolinic acid, potassium salt applied at 0.28 kg a.i. ha^{-1}) plus glyphosate (0.5 kg a.i. ha^{-1}) would provide enough spotted knapweed control to allow establishment of both native and non-native grasses without subsequent re-entry.

Materials and Methods

Study sites

Study site 1 (Rock Creek), initiated in 1994 and continued through 1997, was located about 32 km south of Missoula, Mont. (45° 53' 35"N,113° 59' 35"W) along Rock Creek, at an elevation of 1,160 m. Study site 2 (Hamilton), initiated in 1995 and continued through 1997 was located about 11 km east-northeast of Hamilton, Mont. (46° 17' N, 114° 1' W) at an elevation of 1,341 m. Both sites are on a *Festuca scabrella/Pseudoroegneria spicata* habitat type (Mueggler and Stewart 1980). The Rock Creek site was dominated by spotted knapweed with Kentucky bluegrass, smooth bromegrass (*Bromus inermis* Leyss.), and timothy (*Phleum pratense* L.) growing in association. The Hamilton site was co-dominated by spotted knapweed and cheatgrass. Rock Creek soils were Bigarm gravely loam (loamy-skeletal, mixed, frigid, Typic Eutrochrepts) with zero slope. Hamilton soils were Stecum stony loamy coarse sand (mixed typic Cryorthenths) and were moderately deep. Annual precipitation at both sites ranges from 406 to 457 mm with a bimodal distribution with peaks in the winter and spring. The mean annual temperature at the Rock Creek is 5.0° C and 6.6° C at Hamilton.

Procedures

A fall dormant seeding was applied using 8 herbicide treatments and 3 grass species, with a non-seeded control. Treatments were factorially arranged in a split-plot design with 4 blocks (replications) at each site. The wholeplots were the grass seeding treatments and the subplots were the herbicide treatments.

The herbicide treatments were: none, glyphosate at 0.5 kg a.i. ha^{-1}, picloram at 0.14 kg a.i. ha^{-1}, picloram at 0.28 kg a.i. ha^{-1}, clopyralid (3,6-dichloro-2-pyrdine-carboxylic acid, monoethanolamine salt) at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, picloram 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. h^{-1}, and clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}. Herbicides were applied within 1 day of seeding using a CO_2 pressurized backpack sprayer calibrated to deliver a total volume of 410 liter ha^{-1}. Plots at Rock Creek were sprayed on 5 November 1994. The temperature was 3.3° C, relative humidity was 73%, and winds were calm (< 5 km hr^{-1}). Hamilton plots were sprayed on 7 November 1995. The temperature was 4.2° C, relative humidity was 65%, and the winds were calm (< 5 km hr^{-1}).

Grass species seeded were 'Luna' pubescent wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey], bluebunch wheatgrass [*Pseudorogneria spicata* (Pursh.) Löve], and 'Bozoyski' Russian wildrye [*Psathyrostachys junceae* (Fisch.) Nevski]. Grasses were seeded using a no-till rangeland drill at a rate of 6 kg ha^{-1} to a depth of 4 mm. The grass strips were 2.4 m wide and 63 m long. The Rock Creek site was seeded 6 November 1994 and the Hamilton site was seeded 8 November 1995.

Sampling

Density of seeded grasses and spotted knapweed were determined by counting the number of plants in a 0.2 X 0.5 m frame randomly placed within each plot in July of 1995 (Rock Creek only) 1996 and

1997. Biomass of seeded grass, other grass, and spotted knapweed were determined at peak standing crop in August of 1997 by clipping plants to ground level within a circular hoop 0.44 m^2 randomly placed within each plot. Plants were separated by species, dried (60° C, 48 hr) to a constant weight, and weighed.

Analysis

Analysis of variance was used to determine the effects of herbicide treatment and grass species seeded on density and biomass of seeded grass, spotted knapweed, and other grass. Sites were analyzed separately. The model used for density analysis was a split-split-plot in time with grass species as the whole-plots, herbicide treatments as the sub-plots, and year as the sub-sub-plots. Seeded grass species effects were tested using block by seeded grass species as the error term. Herbicide treatments and herbicide treatments by seeded grass species effects were tested using block by herbicide treatments by seeded grass species as the error term. Year and all year by herbicide treatments and seeded grass species interactions were tested using the residual as the error term. The model used for biomass analysis was a split-plot with seeded grass species as the whole-plots and herbicide treatments as the sub-plots. Seeded grass species effects were tested using block by seeded grass species as the error term. Herbicide treatments and herbicide treatments by seeded grass species effects were tested using the residual as the error term. When a significant P-value ($P \leq 0.05$) was calculated, mean separations for significant main effects and interactions were achieved using Fisher's protected $LSD_{\propto=0.05}$ comparisons (Peterson 1985).

Results

Rock Creek

Spotted knapweed

The effect of herbicide or herbicide combination on spotted knapweed density was dependent upon the year after treatment at Rock Creek (Table 1). All herbicide treatments including either picloram or clopyralid plus 2,4-D yielded similar spotted knapweed density the first (1995) and second (1996) years after application, which ranged from about 3 to 37 plants m^{-2} (Fig. 1a). In 1997, these treatments maintained spotted knapweed densities below that of the control. Picloram applied at 0.28 kg a.i. ha^{-1} or picloram applied at 0.14 kg a.i. ha^{-1} plus glyphosate yielded the lowest density that year, averaging about 108 plants m^{-2}. Spotted knapweed density 3 years after application of picloram applied at 0.14 kg a.i. ha^{-1} and picloram applied at 0.28 kg a.i. ha^{-1} plus glyphosate was 200 and 212 plants m^{-2}, respectively. Treatments that included clopyralid plus 2,4-D yielded similar spotted knapweed density to each other, averaging about 420 plants m^{-2}. Glyphosate increased spotted knapweed density by nearly 55 plants m^{-2} over that of the control in 1995. The density of spotted knapweed was similar to that of the control 2 (1996) and 3 (1997) years after glyphosate application.

Table 1. Mean squares generated from analysis of variance of density at Rock Creek, Mont.

Source	df	Mean Squares: Spotted knapweed	Mean Squares: Seeded grass
Block	3	52,119.9	4,326.0
Species	3	29,344.7	80,043.8*[1]
Block * Species	9	49,561.0	7,760.2
Herbicide	7	988,434.1*	10,899.5*
Species * Herb	21	21,191.1	5,141.5
Block*Herb*Species	84	30,040.8	3,734.1
Year	2	5,287,249.3*	74,258.8*
Year*Species	6	32,171.1	32,541.4*
Year*Herb	14	332,621.4*	7,005.3*
Year*Species*Herb	42	17,585.4	3,838.3
Residual Error	192	25,381.7	3,932.4

[1]Asterisk following mean square indicates significant F-test at $P \leq 0.05$.

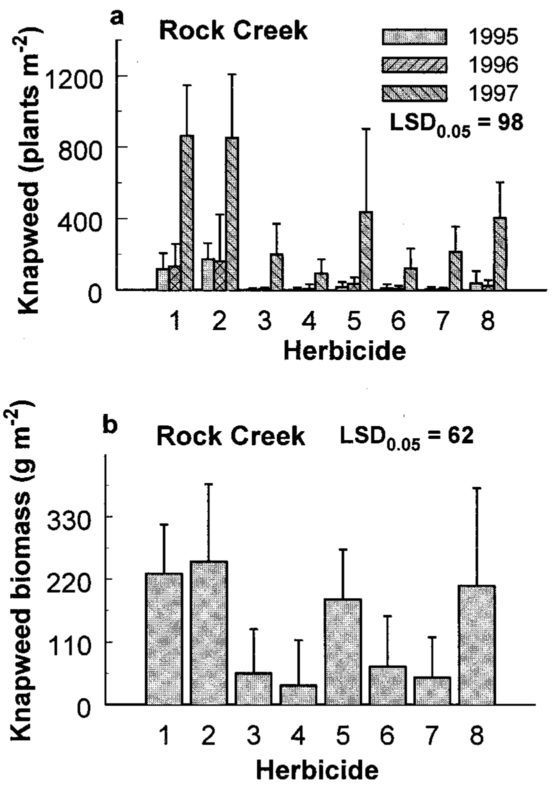

Fig. 1. Effect of herbicide or herbicide combination by year on spotted knapweed density at Rock Creek (1a). Effect of herbicide or herbicide combination on spotted knapweed biomass at Rock Creek (1b). Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

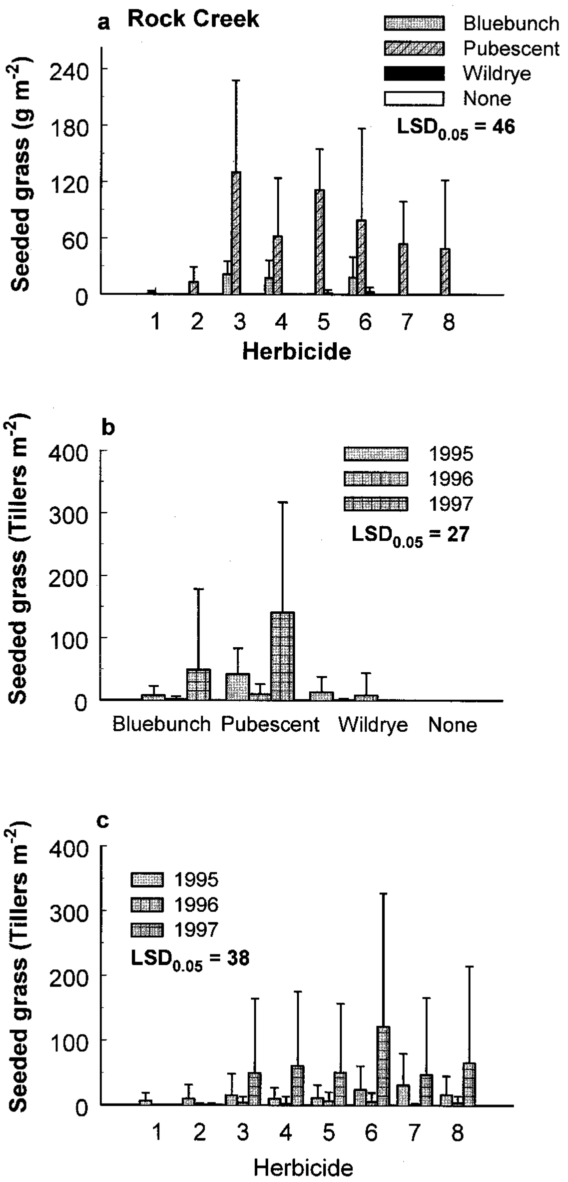

Fig. 2. Effect of herbicide or herbicide combination by year on seeded grass biomass Rock Creek (2a). Effect of species of seeded grass by year on seeded grass density at Rock Creek (2b). Effects of herbicide or herbicide combination by species of grass seeded on seeded grass biomass at Rock Creek (2c). Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

Table 4. Mean squares generated from analysis of variance of biomass (1997) at Rock Creek, Mont.

		Mean Squares			
Source	df	Spotted knapweed	Seeded grass	Other grasses	Other forbs
Block	3	17826	1072	22151*	89
Species	3	6609	25084*[1]	1210	42
Block * Species	9	19320	859	10013	119
Herbicide	7	135534*	2288*	100533*	233*
Species * Herbicide	21	10175	1644*	6424	32

Spotted knapweed biomass was dependent upon the herbicide or herbicide combination in 1997 (Table 2). Those treatments that included picloram yielded the lowest spotted knapweed biomass, ranging from 34 to 67 g m^{-2} (Fig. 1b). All other treatments yielded greater than 185 g m^{-2} of spotted knapweed.

Seeded grasses

The effect of herbicide or herbicide combination on seeded grass was dependent upon the year after treatment at Rock Creek (Table 1). In the first year (1995), those herbicide combinations including glyphosate had the highest seeded grass density (Fig. 2c). However, only picloram applied at 0.28 kg a.i. ha^{-1} plus glyphosate had higher seeded grass density than treatments excluding glyphosate or glyphosate applied alone. In 1996, all treatments produced similar seeded grass density, ranging from 0.6 to 6.3 plants m^{-2}. By 1997, treatments receiving 0.14 kg a.i. ha^{-1} of picloram plus glyphosate had over twice (121 plants m^{-2}) the density of seeded grasses than any other treatments. Glyphosate applied alone produced the lowest seeded grass density (0.6 plants m^{-2}) of all herbicide treatments.

Tiller density of seeded grass was also dependent upon species and year after seeding (Table 1). The first year after seeding (1995) pubescent wheatgrass had the highest grass density at Rock Creek (Fig. 2b). All other species had similar densities to the unseeded control that year. In 1996, all species had similar densities to the unseeded control. Pubescent wheatgrass density was 10 plants m^{-2} that year. By 1997, pubescent wheatgrass had the highest grass density (141 plants m^{-2}). Bluebunch wheatgrass had the second highest density, which was about 49 plants m^{-2}. The density of Russian wildrye was similar to unseeded control at Rock Creek that year.

Seeded grass biomass was dependent upon the species seeded and the herbicide or herbicide combination applied at Rock Creek in 1997 (Table 2). Plots receiving either picloram applied at 0.14 kg a.i. ha^{-1} or clopyralid plus 2,4-D and seeded with pubescent wheatgrass yielded greatest grass biomass (Fig. 2a). Other herbicide treatments including either picloram or clopyralid plus 2,4-D and seeded with pubescent wheatgrass yielded higher grass biomass than seeded with any other species. Biomass of bluebunch wheatgrass and Russian wildrye was similar to the unseeded control. Of the 2 species, bluebunch wheatgrass tended to produce more

Table 3. Mean squares generated from analysis of variance of density at Hamilton, Mont.

Source	df	Mean Squares: Spotted knapweed	Seeded grass
Block	3	1425	19202.8*[1]
Species	3	16178*	80193.2*
Block * Species	9	25152	7367.0
Herbicide	7	149220*	9200.2*
Species * Herb	21	7968	3741.9
Block*Herb*Species	84	7925	2812.3
Year	1	347282*	180613.5*
Year*Species	3	17468*	55883.3*
Year*Herb	7	29376*	2872.8
Year*Species*Herb	21	4308	2452.0
Error	92	6088	3895.9

Table 4. Mean squares generated from analysis of variance of biomass (1997) at Hamilton, Mont.

Source	df	Mean Squares: Spotted knapweed	Seeded grass	Other grasses	Other forbs
Block	3	5875	30	51011	6.7
Species	3	2541	553*[1]	27169*	2.0
Block * Species	9	2566	14	1845	1.8
Herbicide	7	20005*	211*	60915*	4.1
Species * Herbicide	21	1626	89*	6090*	3.8*
Error	93	2107	16	2929	2.0

[1]Asterisk following mean square indicates significant F-test at P ≤ 0.05.

biomass than Russian wildrye. Other grass biomass, primarily smooth bromegrass and Kentucky bluegrass, increased over the unsprayed control and plots sprayed with glyphosate alone at Rock Creek (Fig. 3).

Hamilton

Spotted knapweed

The effect of herbicide or herbicide combination on spotted knapweed density was dependent upon the year after treatment at Hamilton (Table 1). At this site, all herbicide treatments that included picloram produced the lowest spotted knapweed density the first (1996) year after application, which ranged from about 15 to 23 plants m^{-2} (Fig. 4a). Treatments that included clopyralid plus 2,4-D had the highest spotted knapweed density that year. Glyphosate did not affect spotted knapweed density. In 1997, picloram applied at 0.14 kg a.i. ha^{-1}, 0.28 kg a.i. ha^{-1}, and 0.28 kg a.i. ha^{-1} plus glyphosate had 44, 28, and 23 spotted knapweed plants m^{-2}, respectively. Picloram applied at 0.14 kg a.i. ha^{-1} plus glyphosate had slightly higher spotted knapweed density than the other treatments including this herbicide. Treatments that included clopyralid plus 2,4-D or glyphosate alone increased spotted knapweed density over that of the untreated control.

The effect of species on spotted knapweed density depended upon year (Table 3). The first year after seeding (1996) spotted knapweed density was similar to the unseeded control regardless of grass species seeded (Fig. 4b). However, plots seeded with Russian wildrye had fewer spotted knapweed plants than plots seeded with either pubescent wheatgrass or bluebunch wheatgrass. In 1997, all seeded species reduced spotted knapweed density below that of the unseeded control by more than 45 plants m^{-2}.

At Hamilton, spotted knapweed biomass was lowest in those treatments that included picloram in 1997 (Table 4; Fig. 4c). Spotted knapweed biomass ranged from 9 to 15 g m^{-2} in plots treated with picloram. All other treatments yielded spotted knapweed biomass similar to that of the untreated control.

Seeded grasses

Grass density was dependent upon the species and year after seeding (Table 3). In 1996, pubescent wheatgrass and bluebunch wheatgrass had the highest seedling density (about 120 plants m^{-2}) (Fig. 5b). Russian wildrye had 18 plants m^{-2} that year, which was similar to that of the unseeded control. In the second year (1997), all grass species had similar density as that of the unseeded control. However, analysis of variance of the 1997 data alone indicated pubescent wheatgrass and bluebunch wheatgrass had densities higher than that of the unseeded control (Table 3; Fig. 5c).

Seeded grass biomass was dependent upon herbicide or herbicide combination and species of grass seeded (Table 4).

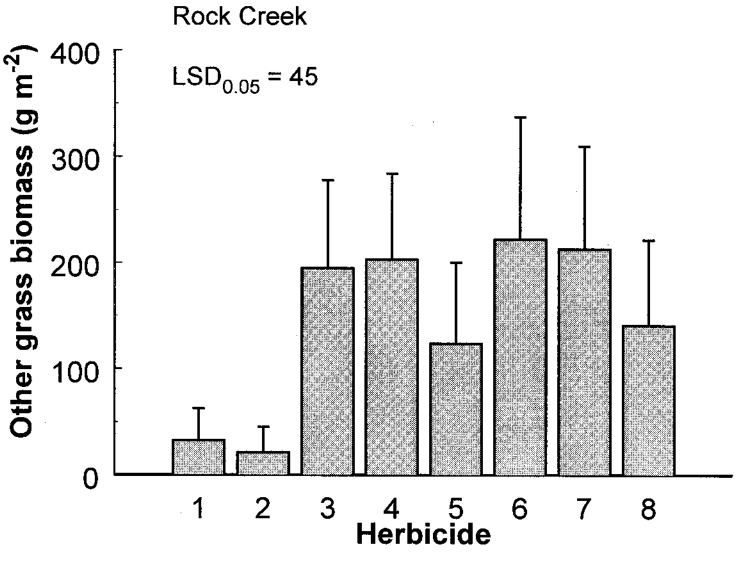

Fig. 3. Effect of herbicide and herbicide combinations on biomass of grasses other than those seeded at Rock Creek. Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

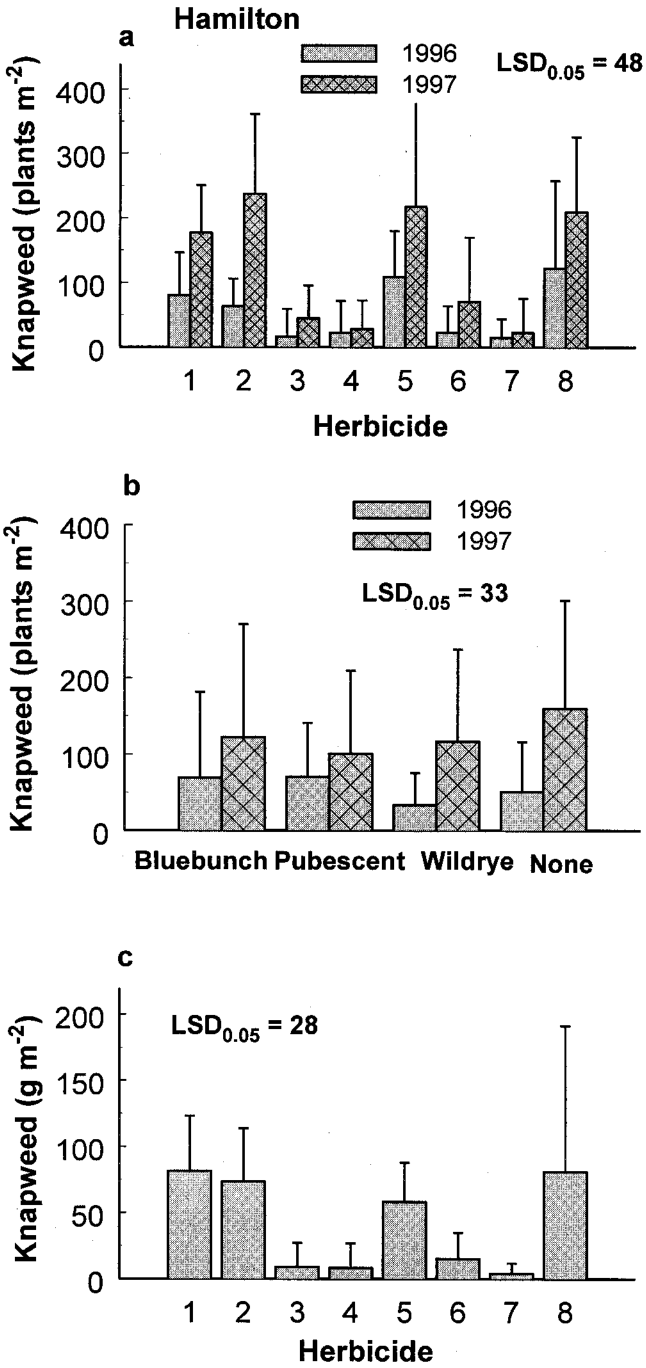

Fig. 4. Effect of herbicide or herbicide combination by year on spotted knapweed density at Hamilton (4a). Effect of species seeded on spotted knapweed density at Hamilton (4b). Effect of herbicide or herbicide combination on spotted knapweed biomass at Hamilton (4c). Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

Pubescent wheatgrass had the greatest biomass in plots where significant establishment occurred (Fig. 5a). Picloram applied at 0.14 kg a.i. ha^{-1} plus glyphosate yielded greatest pubescent wheatgrass biomass, which was 24 g m^{-2}. Picloram applied at 0.28 kg a.i. ha^{-1} yielded 19 g m^{-2} of pubescent wheatgrass biomass. Picloram applied at 0.14 kg a.i. ha^{-1} and picloram applied at 0.28 kg a.i. ha^{-1} plus glyphosate yielded 16 and 15 g m^{-2}, respectively. Plots treated with picloram at 0.28 kg a.i. ha^{-1}, 0.14 kg a.i. ha^{-1} plus glyphosate, or 0.28 kg a.i. ha^{-1} plus glyphosate and seeded with bluebunch wheatgrass had greater grass biomass than the unseeded control. Plots treated with picloram at 0.14 kg a.i. ha^{-1}, 0.14 kg a.i. ha^{-1} plus glyphosate, or 0.28 kg a.i. ha^{-1} plus glyphosate and seeded with Russian wildrye had greater grass biomass than the unseeded control. Clopyralid plus 2,4-D and/or glyphosate did not affect grass biomass.

Cheatgrass biomass was dependent upon herbicide or herbicide combination and species of grass seeded at Hamilton (Table 4). Clopyralid plus 2,4-D and/or glyphosate did not affect cheatgrass biomass (Fig. 6). In all herbicide treatments that included picloram, pubescent wheatgrass yielded the lowest cheatgrass biomass.

Discussion

In many cases, revegetating spotted knapweed infested rangeland fails because of insufficient soil moisture and/or intense weed competition (Velagala et al. 1997). Our study indicates that picloram at either 0.14 or 0.28 kg a.i. ha^{-1} applied in the late-fall provided consistent control of spotted knapweed for up to 3 years. Including glyphosate with picloram did not affect spotted knapweed biomass or the biomass of grasses other than those seeded. In addition, those treatments that included picloram yielded the greatest seeded grass biomass, apparently as a response to effective weed control.

Glyphosate applied alone is often recommended for weed control prior to fall-dormant seeding of many grasses with the objective of controlling all undesirable vegetation for a brief period (Dewey et al. 1997, Jacobs et al. 1998). Glyphosate reduced spotted knapweed and increased grass establishment the first year after application. However, spotted knapweed density increased over the control in subsequent years. Correspondingly, grass establishment was lowest in plots when glyphosate was applied alone. We specu-

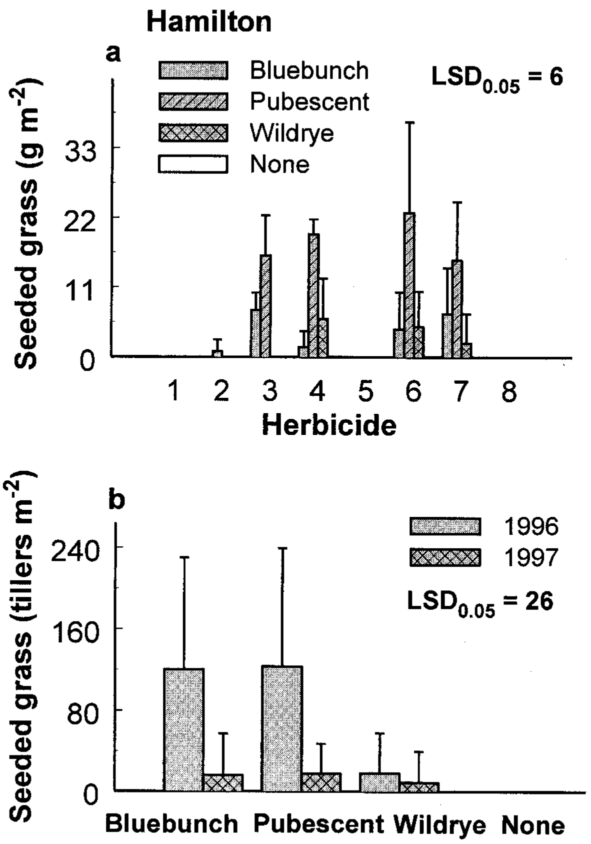

Fig. 5. Effect of species seeded by year after seeding on seeded grass biomass at Hamilton (5a). Effect of herbicide or herbicide combination by species of grass seeded on seeded grass density at Hamilton (5b). Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

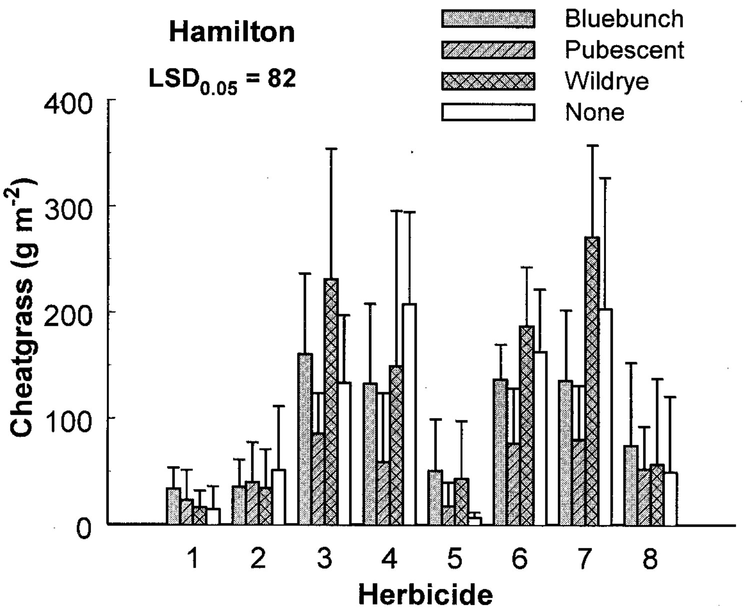

Fig. 6. Effect of herbicide or herbicide combination by species of grass seeded on cheatgrass biomass at Hamilton. Herbicide treatments were: 1) none, 2) glyphosate at 0.5 kg a.i. ha^{-1}, 3) picloram at 0.14 kg a.i. ha^{-1}, 4) picloram at 0.28 kg a.i. ha^{-1}, 5) clopyralid at 0.21 kg a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1}, 6) picloram at 0.14 kg a.i. ha^{-1} plus glyphosate 0.5 kg a.i. ha^{-1}, 7) picloram at 0.28 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}, and 8) clopyralid at 0.21 a.i. ha^{-1} plus 2,4-D at 1.12 kg a.i. ha^{-1} plus glyphosate at 0.5 kg a.i. ha^{-1}.

late that glyphosate temporarily opened niches for both spotted knapweed and seeded grasses the first year. However, by the third season, spotted knapweed out-competed the seeded grasses, and consequently, glyphosate ultimately increased spotted knapweed and resulted in seeding failure.

In treatments where grasses successfully established, 'Luna' pubescent wheatgrass consistently yielded the highest density and biomass. Of 11 grasses studied by Ferrell et al. (1998), 'Luna' pubescent wheatgrass maintained the best stand in no-till drilled plots. In that study, ' Bezoisky' Russian wildrye and 'Luna' pubescent wheatgrass showed the most promise for successful competition with leafy spurge (*Euphorbia esula* L.). However, in this study, 'Bozoisky' Russian wildrye was the poorest establishing grass. 'Goldar' bluebunch wheatgrass, a native species, did not establish as well as 'Luna' pubescent wheatgrass, but based on density and biomass developed a successful stand in plots where picloram was applied.

Although revegetation with aggressive species has been shown to limit weed reinvasion (Lym et al. 1997), managers are reluctant to attempt it because of the number of attempts required for success and the number of entries onto a site needed to maximize the potential for seedling establishment. We believe that a single-entry revegetation program applying picloram in late-fall during a fall-dormant seeding will maximize seedling establishment in spotted knapweed infested rangeland. Our single entry revegetation strategy may provide managers with a cost effective and reliable revegetation strategy and ultimately a sustainable weed management program.

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Intermountain plant community classification using Landsat TM and SPOT HRV Data

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Abstract

Rangeland plant communities of the Intermountain West differ in their ecology and management requirements. Successful management of extensive areas at plant community-level resolution first requires an efficient, cost-effective means of plant community classification and mapping. We evaluated the influence of image acquisition date and satellite imaging system on the accuracy of plant community maps created from multispectral satellite imagery of Reynolds Creek Experimental Watershed (RCEW) (234 km^2) in southwestern Idaho. Maps delineating 6 native and 2 non-native Intermountain plant communities were created from Landsat 5 TM and SPOT 3 HRV data using a maximum likelihood classification procedure. Map accuracy was assessed using ground reference points. Maps created from satellite data acquired during dry-down (early August) had higher overall accuracy ($\bar{x}$ = 70.5%) than from data acquired during peak growth (early June) ($\bar{x}$ = 54.4%). Overall accuracy of maps generated by Landsat ($\bar{x}$ = 60.1%) and SPOT ($\bar{x}$ = 65.5%) were statistically similar. Given their broad spatial coverages (3,600 to 31,450 km^2 scene^{-1}, respectively), moderate resolutions (20 to 30 m pixels, respectively), and potential to provide high classification accuracies, the SPOT 3 HRV and Landsat 5 TM satellite systems were well-suited for classifying plant communities in the Reynolds Creek Watershed and similar areas of the Intermountain West. Practical procedures for plant community classification and map accuracy assessment are presented for use by natural resource managers.

Key Words: Cover type, maximum likelihood, multispectral, rangeland, remote sensing, satellite imagery, supervised classification, vegetation.

Resumen

Las comunidades de plantas del los pastizales intermontanos del oeste difieren en su ecología y requerimientos de manejo. El manejo exitoso de áreas extensivas a nivel de resolución de comunidad de plantas, primero, requiere un medio eficiente y efectivo en términos de costos para el mapeo y clasificación de las comunidades de plantas. Evaluamos la influencia de la fecha de adquisición de imagenes y del sistema de imagen de satélite en la certeza de los mapas de comunidades de plantas creados a partir de imágenes multiespectrales de satélite de la Cuenca Hidrológica Experimental "Reynolds Creek" (RCEW) (234 km^2) del suroeste de Idaho. Se crearon mapas delineando 6 comunidades de plantas intermontanas nativas y 2 comunidades no nativas a partir de datos de Landsat 5 TM y SPOT 3 HRV utilizando el procedimiento de clasificación de máxima probabilidad. La certeza del mapa se evaluó utilizando puntos de referencia terrestres. La certeza de los mapas creados de datos de satélite adquiridos durante época seca (inicios de Agosto) tuvieron una certeza general más alta ($\bar{x}$ = 70.5%) que los datos adquiridos durante el pico de crecimiento de las plantas (inicios de Junio) ($\bar{x}$ = 54.4%). La certeza general de los mapas generados por Landsat ($\bar{x}$ = 60.1%) y SPOT ($\bar{x}$ = 65.5%) fueron estadísticamente similares. Dada su amplia cobertura espacial (3,600 a 31,450 km^2 escena^{-1}, respectivamente), resoluciones moderadas (20 a 30 m por pixel respectivamente) y el potencial para proveer certezas de clasificación altas, los sistemas de satélites SPOT 3 HRV y Lansat 5 TM fueron apropiados para clasificar las comunidades de plantas en la Cuenca Hidrológica "Reynolds Creek" y áreas similares de la región intermontana del oeste. Se presentan procedimientos prácticos para evaluar la certeza de la clasificación y mapeo de las comunidades de plantas para el uso por manejadores de recursos naturales.

The Intermountain region of the western United States is dominated by extensive rangelands containing a diverse assemblage of plant communities differing in their ecology and management needs. Classification and mapping plant communities across extensive areas by conventional methods, such as aerial photograph interpretation and ground survey, can often be cost prohibitive. Consequently, managers of these rangelands commonly lack the appropriate spatial information needed to properly manage these plant communities.

Multispectral satellite imagery can be efficiently used for vegetation classification and mapping on extensive rangelands (Tueller 1989, Pickup et al. 1994). Although satellite-based classification and mapping techniques for rangeland vegetation have been developed, tested and refined for nearly 3 decades (e.g., Tueller et al. 1975, Graetz and Gentle 1982, Kremer and Running 1993, Jakubauskas et al. 1998), range managers have not yet embraced this technology. Inadequate computer hardware/software and high imagery costs no longer constrain rangeland application of satellite technology. A lack of remote sensing training in range managers seems to be the only critical limitation to adoption of satellite-based rangeland management tools.

To address the need for accurate, up-to-date plant community maps and to facilitate in-service training in remote sensing, range

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managers in the Intermountain region need a set of practical procedures for plant community classification and mapping using multispectral satellite imagery. Objectives of this study were to: (1) compare the accuracy of 2 satellite remote sensing systems, Landsat 5 TM and SPOT 3 HRV, for Intermountain plant community classification, 2) evaluate the effects of imagery acquisition date on Intermountain plant community classification accuracy, and 3) present a set of practical procedures and recommendations for use by range managers to classify and map Intermountain plant communities using satellite imagery.

Materials and Methods

Study Area

The study was conducted in the Reynolds Creek Experimental Watershed (RCEW) located 80 km south of Boise in southwestern Idaho (43° 11' N, 116° 46' W). The RCEW is 234 km^2 in extent and ranges in elevation from 1,097 m to 2,252 m (Fig. 1). The area is typical of the shrub steppe and subalpine rangelands occurring throughout the Intermountain region. Mean annual precipitation at the Watershed ranges from 250 mm at lower elevations to 1,270 mm at higher elevations but is also affected by position relative to incoming storms. Locations on the western side of the Watershed receive about 1.5 times more precipitation than those on the eastern side at the same elevation. About 75% of the precipitation in the higher elevations falls as snow. Summers are very dry throughout the Watershed.

Soils in the Reynolds Creek Watershed are derived primarily from basalt (63% of the Watershed), granite (18%), alluvium/lacustrine sediments (12%) and welded tuff (6%) (Stephenson 1977). Aridisols dominate the lowest elevations and Mollisols are most common elsewhere. Soils derived from granite are generally in coarse-loamy families and the others are generally in fine loamy families. Except in valley bottoms and snow drift areas, soils are shallow, rocky and steep.

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle and Young) and salt desert shrub are the dominant native plant communities in the lower elevations (< 1,400 m) of the Watershed. Principal species in the Wyoming big sagebrush community are Wyoming big sagebrush, bluebunch wheatgrass (*Pseudoroegneria spicata* [Pursh] A. Löve), and Sandberg bluegrass (*Poa secunda* J. Presl.) (Spaeth et al. 2000). Greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.), bud sagebrush (*Picrothamnus desertorum* Nutt.), spiny hopsage (*Grayia spinosa* [Hook.] Moq.), and squirreltail (*Elymus elymoides* [Raf.] Swezey) dominate the salt desert shrub community. Cultivated hay fields and Siberian wheatgrass (*Agropyron fragile* [Roth] P. Candargy) seedings also occur in the lower elevations of the Watershed. The hay fields are primarily flood-irrigated fields of orchardgrass (*Dactylis glomerata* L.). The Siberian wheatgrass seedings were degraded stands from the Wyoming big sagebrush and salt desert shrub communities which were prescribed burned and seeded to Siberian wheatgrass in 1984.

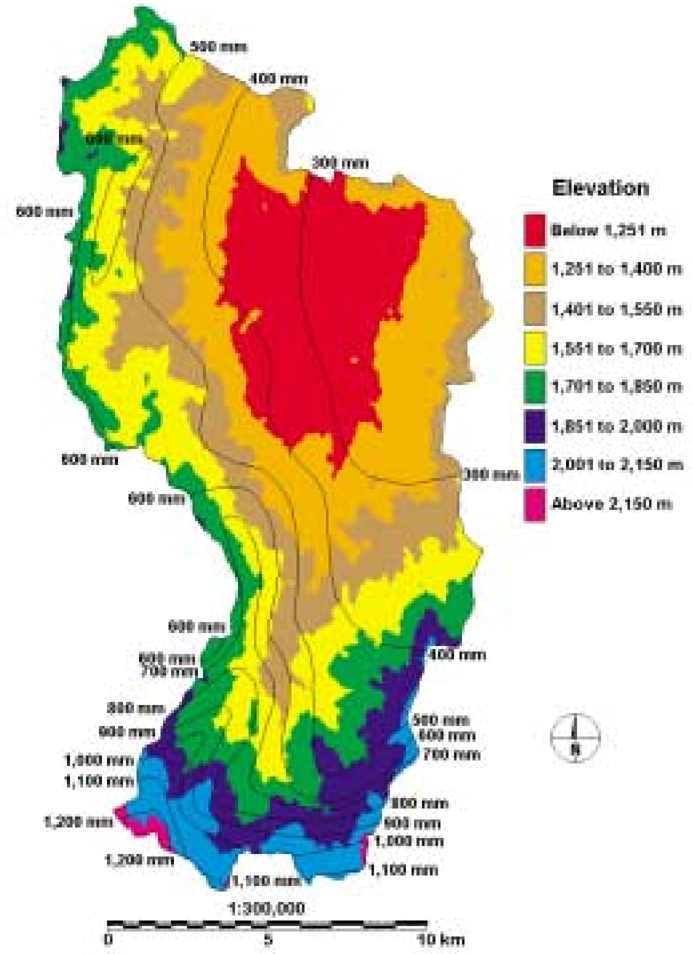

Fig. 1. Elevation (shaded polygons) and annual precipitation (line contours) of Reynolds Creek Experimental Watershed in southwestern Idaho.

Low sagebrush and big sagebrush/bitterbrush plant communities are the dominant vegetation in the mid elevations (1,400 m to 1,600 m). Low sagebrush (*Artemisia arbuscula* Nutt.), Sandberg bluegrass, and arcane milkvetch (*Astragalus obscurus* S. Wats.) are the principal species of the low sagebrush community (Spaeth et al. 2000). Wyoming big sagebrush, antelope bitterbrush (*Purshia tridentata* [Pursh] DC.), bluebunch wheatgrass, and Idaho fescue (*Festuca idahoensis* Elmer) dominate the big sagebrush/bitterbrush community.

Mountain big sagebrush, aspen, and mixed-conifer are the dominant plant communities in the higher elevations (> 1,600 m). The principal species in the mountain big sagebrush community are mountain big sagebrush (*Artemisia tridentata* Nutt. ssp. *vaseyana* [Rydb.] Beetle), mountain snowberry (*Symphoricarpos oreophilus* Gray), mountain brome (*Bromus marginatus* Nees ex Steud.), elk sedge (*Carex garberi* Fern.), lupine (*Lupinus* L.), and sticky cinquefoil (*Potentilla glandulosa* Lindl.) (Spaeth et al. 2000). The aspen community is characterized by a tree overstory of quaking aspen (*Populus tremuloides* Michx.) and an herbaceous understory of mountain brome, western needlegrass (*Achnatherum occidentale* [Thurb. ex S. Wats.] Barkworth), Kentucky bluegrass (*Poa pratensis* L.), veiny meadowrue (*Thalictrum venulosum* Trel.), and mountain sweetroot (*Osmorhiza chilensis* H. &

A.). Douglas- fir (*Pseudotsuga menziesii* [Mirbel] Franco) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) form the tree overstory of the mixed-conifer community. Western needlegrass, elk sedge, veiny meadowrue, and mountain sweetroot occur as a sparse understory.

Satellite Data and Preprocessing Levels

Landsat 5 TM scenes acquired 6 June 1996 and 1 August 1993 were purchased from Space Imaging[1] (formerly EOSAT Corp., Thornton, Colo.). The SPOT 3 HRV scenes acquired 17 June 1993 and 16 August 1994 were purchased from SPOT Image Corp.[1] (Reston, Virg.). Landsat 5 TM acquires data in 3 visible bands, blue (0.45 to 0.52 m), green (0.52 to 0.60 m), and red (0.63 to 0.69 m), 1 near-infrared band (0.76 to 0.90 m), 2 mid-infrared bands (1.55 to1.75 and 2.08 to 2.35 m), and 1 thermal infrared band (10.4 to 12.5 m) of the electromagnetic spectrum. Landsat 5 TM stores data from the visible, near-infrared and mid-infrared bands as 30-m pixels with 8-bit radiometric resolution (256 brightness levels). Landsat 5 TM stores thermal infrared data as 120-m pixels. Landsat 5 has a sun-synchronous, near-polar orbit with a 16-day repeat cycle. The ground swath width of the Landsat 5 TM is 185 km and Landsat scenes are 185 km by 170 km (31,450 km^2) in size.

The SPOT 3 HRV acquires data in 2 visible bands, green (0.50 to 0.59 m) and red (0.61 to 0.68 m) and 1 near-infrared band (0.79 to 0.89 m) of the spectrum. The SPOT 3 HRV color and near-infrared imagery are stored as 20-m pixels with 8-bit radiometric resolution. The SPOT 3 HRV also has a panchromatic band with a 10-m pixel size. The SPOT 3 has a sun-synchronous, near-polar orbit with a 26-day orbit cycle. Pointable optics on SPOT 3 permit off-nadir viewing which can decrease the time intervals between viewing opportunities. The SPOT 3 HRV scenes are 60 km by 60 km (3,600 km^2) in size. The Landsat and SPOT scenes used in this study were cloud-free and had been radiometrically- and geometrically-corrected (Level 1B data) by the vendor. A subscene representing the areal coverage of the Reynolds Creek Watershed (RCEW) was extracted from each scene using an image processing software package (PCI, Richmond Hill, Ontario, Canada). These subscenes were precision-corrected (georectified) using ground control points located with a GPS but were not terrain-corrected.

[1]Mention of manufactures or trade names is for the convenience of the reader only and implies no endorsement on the part of the authors, USDA, or University of Idaho.

Plant Community Classification

The primary objective of image classification is to place all pixels in an image into discrete vegetation cover classes. Vegetation cover classification is based on recognition of spatial, temporal, or spectral patterns in multispectral imagery. Spectral pattern recognition is the most commonly used form. Different vegetation cover types have different combinations of spectral reflectance and emittance properties. These spectral patterns are captured on multispectral imagery and manifested as different combinations of digital numbers (DN), thus, providing a numerical basis for vegetation cover type classification (Lillesand and Kiefer 1994).

There are 2 spectral pattern-based methods, supervised and unsupervised classification, commonly used for vegetation cover type classification (Lillesand and Kiefer 1994). In the supervised approach, the vegetation cover types to be mapped as classes are specified initially. Spectral signatures for each of these classes are generated from spectral information acquired from imagery pixels corresponding to field sites representative of each class. These sites are called training areas. Classifier algorithms then statistically compare each image pixel to these spectral signatures and assign the pixel to the cover class it most closely resembles. In the unsupervised approach, clustering algorithms are used to aggregate image pixels into spectrally separable classes. The vegetation cover type associated with each class is determined *a posteriori* by comparing the classified image data to ground reference data.

Although rangeland vegetation can be successfully classified using either supervised or unsupervised classification (Tueller 1989), both involve a certain amount of trial and error before a satisfactory result is obtained. An approach which combines both classification methods can often be more efficient. Range managers are typically aware of the dominant vegetation cover types on a landscape of interest and would include these as classes in a supervised classification. Failure to recognize and include other spectrally-separable cover classes will, however, inflate the number of unclassified or misclassified pixels resulting from a supervised classification. By initially applying an unsupervised classification to the imagery data set, these other cover classes can be identified and included in a subsequent supervised classification.

In this study, an unsupervised classification (K-means clustering) was initially applied to the Landsat and SPOT subscenes. Although the spectral classes generated by the initial run of K-means clustering procedure did not exhibit an obvious spatial relationship with the native plant communities or cultivated grass hay fields known to be present in the Reynolds Creek Watershed, application of this unsupervised classification identified the need to include the burned and seeded area as a separate class in the supervised classification described below.

Classifier training areas were established in the 9 dominant plant communities, including 7 native communities (salt desert shrub, Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, mountain big sagebrush, aspen, and mixed-conifer) and 2 non-native communities (cultivated grass hay and Siberian wheatgrass), occurring in the Watershed. Selection of these 9 communities was based on information gathered from field survey, existing vegetation maps of the Reynolds Creek Watershed, and rangeland cover type descriptions published in Shiflet (1994). Riparian, mountain meadow and other plant communities of small spatial extent were not included in order to simplify the analysis and reduce classification errors associated with mixed pixels (see discussion below). To ensure the training areas were representative of the vegetation on the Watershed, 4 to 5 training areas were established in each plant community. These training areas were located on relatively flat terrain to minimize topography-induced effects on the reflectance values of the imagery. Training areas were established within large patches of relatively homogenous vegetation from each respective plant community. Inclusion of non-target cover types within the training areas was avoided. A Global Positioning System (GPS) with a horizontal accuracy of ± 2 m was used to establish the training area perimeter ≥ 30 m (i.e., a Landsat pixel width) interior to the edge of the patch. This 30-m buffer zone around each training area helped minimize inclusion of mixed pixels (pixels which span more than 1 plant community). Each training area was at least 5.4 ha in size or large enough to contain at least sixty, 30-m pixels. This minimum size criteria for training areas is based on the following equation:

$$P = (5(n^2 + n)) \qquad \textbf{(1)}$$

where P is the minimum number of image pixels required per training area and n is the number of spectral bands to be used in the classification (PCI 1998). In this case, 3 spectral bands were used (see below). A training area of adequate size could not be established in the salt desert shrub community, however, without obtaining some inclusions of the Wyoming big sagebrush community. Impure salt desert shrub training areas probably contributed to classification errors between this community and the Wyoming big sagebrush community.

A bitmap image mask of each training area was generated with an image-processing software package (PCI, Richmond Hill, Ontario, Canada) using the perimeter coordinates obtained from the GPS survey. Four sets of spectral signatures for each training area were developed (1 for each satellite system/date combination) using green, red, and near-infrared reflectance data from image pixels located under the corresponding image masks. The green, red, and near-infrared combination was used because preliminary experimentation with different band combinations indicated this combination would provide the best image classification for these data sets. To ensure good statistical representation of the spectral characteristics of each plant community, spectral signatures from 2 to 3 training areas per community were merged to form a single signature per community.

Selection of the spectral signatures to be merged was based on their separability from signatures of other plant communities. Signature separability was analyzed using a transformed divergence procedure (Swain and Davis 1978). Transformed divergence values theoretically range from 0 to 2. A value of 0 indicates the spectral signatures from a pair of classes are completely inseparable and a value of 2 indicates complete separability. Transformed divergence values below 1.9 tend to be poorly separable. The signature separability between the salt desert shrub and Wyoming big sagebrush plant communities was very poor for all training areas. Transformed divergence values comparing the spectral signatures of these 2 communities ranged from 1.09 to 1.76 depending on which of the 4 date/system image combinations was used. Consequently, the salt desert shrub community was not treated as a separate class in successive analyses. Merged signatures were generated from all 4 satellite images using the same training area combinations for the 8 remaining plant communities.

The Gaussian maximum likelihood classifier was used to classify the pixels from each subscene into 8 plant community classes based on their spectral signatures. The maximum likelihood classifier typically provides higher classification accuracy than the other 2 commonly used supervised classification techniques; minimum-distance-to-means and parallelepiped. Although the maximum likelihood classifier is much more computationally complex than the other 2 classifiers, recent advances in computer hardware have essentially nullified this disadvantage.

Initial evaluation of the 4 resultant classification maps revealed that some high elevation pixels had been classified as cultivated land. Cultivated land in the study area was actually localized around the lower reaches of Reynolds Creek and its larger tributaries. The classifier appeared to be confusing aspen stands and mountain meadows at high elevations with cultivated land. A simple correction model was applied to the maps, reassigning cultivated land pixels of greater than a threshold elevation to the aspen class. Mountain meadows were not mapped as a separate class because they occupied only an extremely small fraction of the study area.

Accuracy Assessment

There are several measures commonly used to assess vegetation cover type classification accuracy. Overall accuracy is a percentage of reference pixels from all cover types which were correctly classified. Overall accuracy is essentially a weighted mean of all individual cover type accuracies. Producer accuracy is a percentage of reference pixels representing a specific cover type which were correctly classified to that cover type. Errors of omission (exclusion) decrease producer accuracy. Producer accuracy is commonly used as an indicator of training area quality during map product development (Lillesand and Kiefer 1994). User accuracy indicates the percentage of pixels classified to a specific cover type when they truly represent that cover type. Errors of commission (inclusion) decrease user accuracy. When a range manager identifies a feature mapped as a specific cover type, the user accuracy indicates the likelihood that feature truly has the same cover type in the field. Consequently, user accuracy is commonly used to express the accuracy of cover type map products. Accuracy comparisons in this study were based on user accuracy values.

Two ground truth data sets were collected to assess the accuracy of the 4 vegetation maps (Fig. 2 to 5). An initial map accuracy assessment was performed using a 1 by 2-km grid of reference points established across the Watershed by field visits with a GPS. This grid contained a total of 146 points. Of those, 46 points were discarded either because they were located on small patches (< 3 by 3 pixels) of a target plant community or on a plant community we were not evaluating (e.g., Juniper Woodland). The remaining 100 points provided data representative of the areal extent of those plant communities found in the Watershed. This data set was used to evaluate acquisition date and satellite system effects on vegetation map accuracy. Because of small sample sizes in some plant communities, this initial accuracy comparison between maps was limited to the 4 plant communities having the greatest land cover in the Watershed: (1) Wyoming big sagebrush, (2) low sagebrush, (3) big sagebrush/bitterbrush, and (4) mountain big sagebrush.

The second ground truth data set was developed so that the classification accuracy for all 8 plant communities investigated in the Watershed could be assessed. Thirty sample points from each of the 8 communities were randomly selected from the map exhibiting the highest initial accuracy. Each of these 240 sample points was classified to a reference plant community by interpretation of 1:12,000 scale color-

Table 1. Main effects and interactions, with their respective p-values, for user accuracy of plant community maps created using Landsat 5 TM and SPOT 3 HRV multispectral data acquired during peak vegetation growth (June) and late summer dry-down (August) in the Reynolds Creek Experimental Watershed in southwestern Idaho.

Main Effects and Interactions	Degrees of Freedom	P-Values
S[1,2]	1	0.4816
D[2]	1	**0.0450**[3]
C	3	0.3545
S*D[2]	1	0.1672
S*C	3	0.1750
D*C	3	0.3123

[1]S = Satellite system, D = Acquisition date, and C = Plant community (Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush).
[2]Effects of satellite system, acquisition date and their interaction were calculated based on means which were weighted by sample size while plant community effects and interactions were calculated based on unweighted means.
[3]P-values < 0.05 are printed in bold face

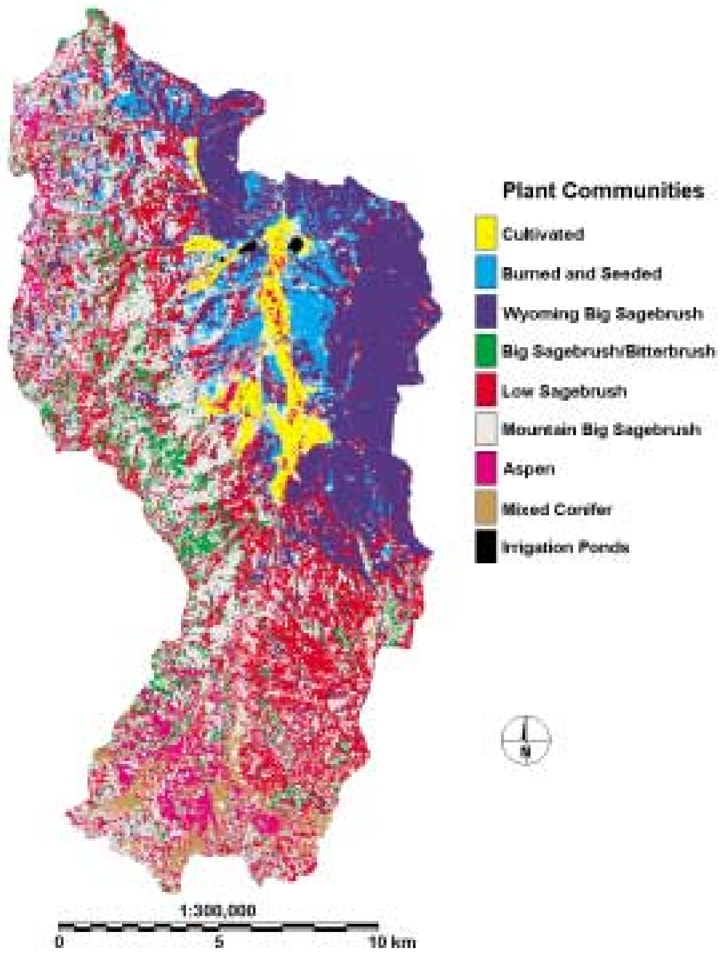

Fig. 2. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a Landsat 5 TM image acquired 6 June 1996.

infrared aerial photography acquired 1 August 1987. Accuracy of the aerial photograph interpretation was assumed to be 100%. Field visits to a 10% sample of reference points from each class confirmed this assumption. This type of intensive accuracy assessment was only applied to the map with the highest initial accuracy because it was not logistically feasible to establish a new set of 240 reference points for each of the other 3 maps.

Statistical Analysis

The effects of acquisition date, satellite system, and their interaction were examined using a weighted General Linear Model (GLM) procedure (SAS 1988) (Table 1). Weighting allowed calculation of mean overall accuracies for the acquisition date and satellite system comparisons. Weighting was based on the number of reference points located in each plant community class. The effect of plant community and its interactions with acquisition date and/or satellite system were analyzed using an unweighted GLM procedure. Where significant effects were detected, Fisher's Least Significant Difference (LSD) procedure was used for mean separations at a 5% level of significance. The scope of inference for this study is limited to the Reynolds Creek Experimental Watershed.

Results and Discussion

Plant Community Map Accuracy

Maximum likelihood classification of Landsat data acquired during dry-down (1 August 1993) produced a highly accurate map (73.6% overall accuracy) of the Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush communities in the Watershed (Fig. 3, Table 2). The low sage community (82.6% user accuracy) tended to be the most accurately mapped while the big sagebrush/bitterbrush community (64.3% user accuracy) tended to be the least accurately mapped of these 4 plant communities. Low sagebrush and mountain big sagebrush communities were often misclassified as the big sagebrush/bitterbrush community in maps from all 4 date/system combinations, particularly in the SPOT 17 June 1993 map (Fig. 4, Table 3). The spectral separability between low sagebrush and big sagebrush/bitterbrush was poor to very poor. Transformed divergence values comparing the spectral signatures of these 2 communities ranged from 1.38 to 1.89 depending on which of the 4 date/system image combinations was used. Mountain big sagebrush and big sagebrush/bitterbrush exhibited poor separability (TD value = 1.83) when the 1 August 1993 Landsat data were used. In the Watershed, bitterbrush can occur as widely-scattered plants within low sagebrush and mountain sagebrush communities, particularly on ecotone sites. Bitterbrush may have a dominate spectral signature which confuses the classifier even when bitterbrush cover is very low.

Based on this initial accuracy assessment, the most accurate map (1 August 1993 Landsat map) was selected for the more intensive accuracy assessment involving all 8 plant communities. The

Table 2. Percentage overall user accuracy and user accuracy by plant community for maps of 4 sagebrush communities created by maximum likelihood classification of Landsat 5 TM and SPOT 3 HRV imagery acquired during peak greenness (June) and dry down (August) at Reynolds Creek Experimental Watershed in southwestern Idaho based on 79 points from 100-point reference grid.

		User Accuracy by Plant Community			
Satellite Imagery[1]	Overall User Accuracy[2]	Wyoming B. Sagebrush	B. Sagebrush Bitterbrush	Low Sagebrush	Mountain B. Sagebrush
		-------------------------%-------------------------			
LSAT 6_96	45.7	67.9	75.0	48.0	12.5
SPOT 6_93	63.3	70.0	36.4	68.0	61.5
LSAT 8_93	73.6	75.0	64.3	82.6	66.7
SPOT 8_94	67.4	60.0	50.0	85.7	76.9

[1]LSAT 6_96 = Landsat 5 TM image acquired June 6, 1996, SPOT 6_93 = SPOT 3 HRV image acquired 17 June 1993, LSAT 8_93 = Landsat 5 TM image acquired 1 Aug. 1993, and SPOT 8_94 = SPOT 3 HRV image acquired16 Aug. 1994.
[2]Weighted mean user accuracy

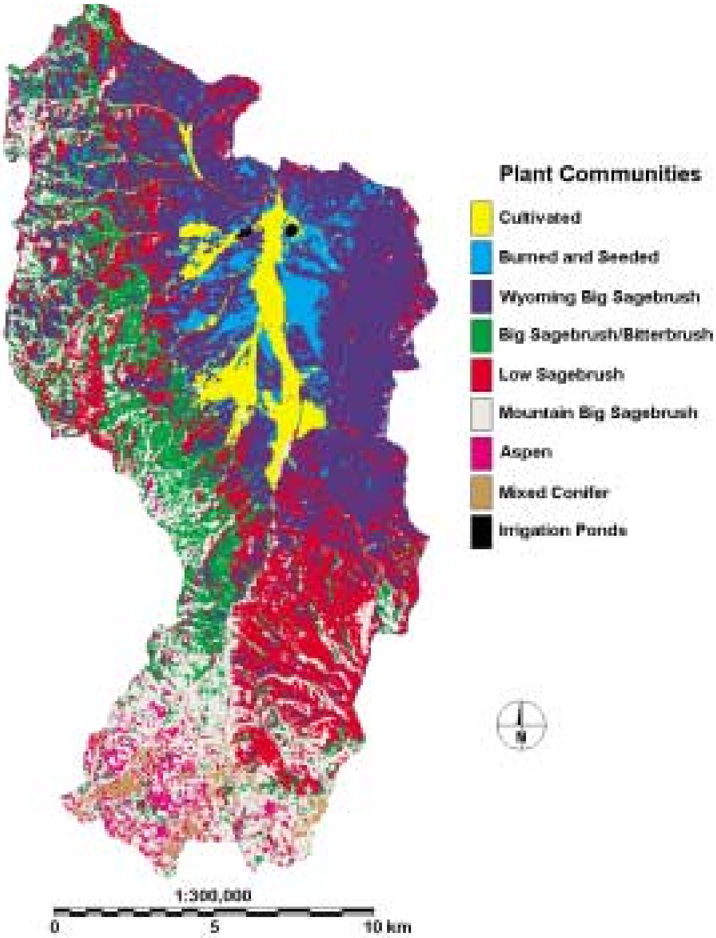

Fig. 3. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a Landsat 5 TM image acquired 1 August 1993.

overall accuracy for this map was 83.8% based on the 240 references points randomly selected from the map (Table 4). The low sagebrush community was mapped with 100% user accuracy and thus was the most accurately mapped of the 8 communities. User accuracy for the big sagebrush/bitterbrush community (66.7%) was the poorest of the 8 communities. As detected in the initial accuracy assessment, low sagebrush and mountain big sagebrush were often misclassified as big sagebrush/bitterbrush by the classifier (Table 5). The classifier also had problems with the 3 high elevation communities. Aspen and mountain big sagebrush pixels were sometimes misclassified as mixed conifer. Broadleaf and conifer trees typically have similar signatures in the red and green bands but differ in the near infrared band (Lillesand and Kiefer 1994). Performing a second classification run, on areas initially mapped as broadleaf (e.g., aspen) or conifer trees, using signatures generated from only the near infrared band may improve classification accuracy for these communities.

The salt desert shrub community was not treated as a separate class because of its low spectral separation with the Wyoming big sagebrush community. It was assumed any salt desert shrub stands would be mapped as Wyoming big sagebrush. Field visits and a qualitative comparison of the 1 August 1993 Landsat map with an older plant community map, created using ground survey and photograph interpretation color aerial photographs (acquired 11 June 1961), tended to confirm this assumption. Some salt desert shrub stands delineated on the 1961 plant community map, however, occurred in an area that was prescribed burned and seeded to Siberian wheatgrass in 1984. This burned and seeded area was correctly classified by the maximum likelihood classifier.

The salt desert shrub stands in the Experimental Watershed occur in what appears to be an ecotone between the salt desert shrub and Wyoming big sagebrush communities. It may have been possible to delineate the salt desert shrub community from Wyoming big sagebrush if the salt desert shrub training areas had been established in more extensive, "pure" stands outside of the Watershed.

Acquisition Date and Satellite System Effects

Imagery acquisition date significantly influenced overall user accuracy of maps delineating the Wyoming big sagebrush, big sagebrush/bitterbrush, low sagebrush, and mountain big sagebrush communities within the Reynolds Creek Watershed (Table 1, Fig. 2 to 5). Landsat and SPOT data acquired during dry-down (early August) produced more accurate plant community maps ($\bar{x}$ = 70.5% overall accuracy) than data acquired during peak growth (early June) ($\bar{x}$ = 54.4% overall accuracy). Overall accuracy of maps generated by Landsat ($\bar{x}$ = 60.1%) and SPOT ($\bar{x}$ = 65.5%) were statistically similar. No significant plant community main effect or interactions with acquisition date or satellite system were detected (Table 1).

Similar to our results, Jakubauskas et al. (1998) reported the separability of spectral

Table 3. Maximum likelihood classifier performance for 4 sagebrush communities in Reynolds Creek Experimental Watershed in southwestern Idaho using SPOT 3 HRV imagery acquired 17 June 1993 and based on 79 points from a 100-point reference grid.

	Classifier Output (y) Native Sagebrush Communities[1]				
True Class (x)	WYMSG	SGBIT	LOWSG	MNTSG	Total pixels in each true class
WYMSG	21[2]	1	5	2	29
SGBIT	1	4	1	2	8
LOWSG	8	4	17	1	30
MNTSG		2	2	8	12
Total pixels in each output class	30	11	25	13	79

[1]Native sagebrush communities where, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, and MNTSG = mountain big sagebrush community
[2]Each entry indicates the number of pixels the classifier has placed in each respective class y, when in fact they belong to true class x.

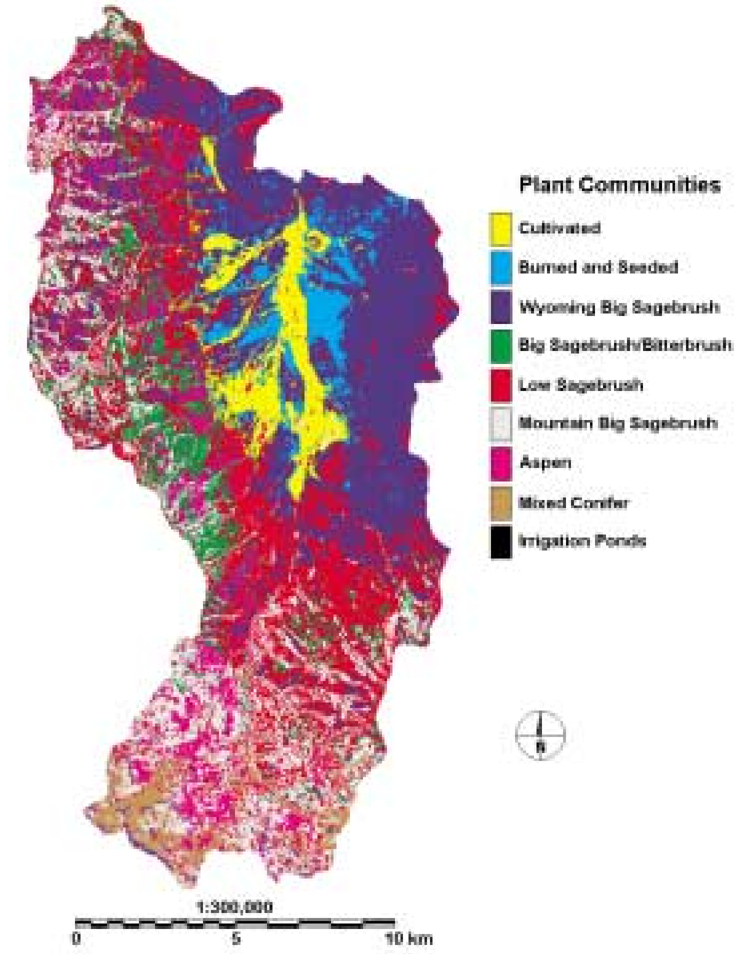

Fig. 4. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a SPOT 3 HRV image acquired 17 June 1993.

signatures generated from Indian IRS LISS-II multispectral data for 4 sagebrush steppe communities was poor during peak greenness in June and greatest in August and decreased in October as plants became completely senescent. Extensive differences exist in the phenologies of the major plant species in the sagebrush steppe (Blaisdell 1958). Phenological development affects the spectral characteristics of plants (Huete and Jackson 1987). These phenological effects vary among species and growth forms (Duncan et al. 1993, Franklin et al. 1993, Bork et al. 1998). Phenological differences probably affect the spectral characteristics of plants most during the late season (August) when some plants are still green or have ephemeral leaves intact, some are drying down or dropping leaves, and some are already completely senescent. Consequently, the spectral combinations forming individual cover type signatures would be more complex in August than in June, and this could result in greater spectral separability for some cover types in August. Additionally, because precipitation in the Intermountain West is typically higher in June, wet soil surfaces are more common in June than August. Spectral signatures of wet soils are less separable from sagebrush steppe vegetation than dry soils (Bork et al. 1998), effectively simplifying the spectral signatures of sagebrush communities in June and possibly reducing the spectral separation between these communities.

Sources of Classification Error

There are several important sources of classification error than should be considered when developing a plant community mapping project using satellite imagery. Poor georegistration of imagery can produce considerable classification error, particularly for communities which occur as small patches. If only the scene corner and center coordinates (provided in the scene header by the vendor) are used to georectify system-corrected imagery (Level 1-B), the horizontal accuracy would be ± 250 m. On relatively flat areas, horizontal accuracy can be substantially increased with inclusion of additional ground control points in the georectification process. In more rugged areas, however, it is unlikely additional ground control points will correct terrain-induced displacements which can produce considerable classification error (Dymond 1988, 1992) and reduce map accuracy. A digital elevation model and additional ground control points are required to correct for terrain displacement. Imagery used in this study was not terrain-corrected and misclassification of some reference pixels was clearly due to inadequate georectification. Where the relief is greater than 500 m, terrain-corrected imagery is recommended for accurate mapping.

Poor spectral separability between plant communities classes can lead to poor classification accuracy. Selection of training

Table 4. Accuracy Statistics for Maximum Likelihood Classification of 8 plant communities in Reynolds Creek Experimental Watershed in southwestern Idaho using Landsat 5 TM multispectral imagery acquired 1 August 1993 based on an accuracy assessment using 240 randomly located reference points.

Overall Accuracy: 83.8% 95% Confidence Interval: 78.9–88.6%
Overall Kappa Statistic: 0.814% Overall Kappa Variance: 0.001%

Class	Producer Accuracy	95% Confidence Interval	User Accuracy	95% Confidence Interval	Kappa Statistic
	----------------	----------------	%----------------	----------------	----------------
CULTV[1]	96.6	88.2 –104.9	93.3	82.7 – 103.9	0.92
BURND	100.0	98.0 – 102.0	83.3	68.3 – 98.3	0.81
WYMSG	84.4	70.2 – 98.5	90.0	77.6 – 102.4	0.88
SGBIT	90.9	76.6 – 105.2	66.7	48.1 – 85.2	0.63
LOWSG	63.8	49.0 – 78.6	100.0	98.3 – 101.7	1.00
MNTSG	75.0	58.4 – 91.6	80.0	64.0 – 96.0	0.77
ASPEN	85.7	71.0 – 100.5	80.0	64.0 – 96.0	0.77
CONIF	92.0	79.4 – 104.6	76.7	59.9 – 93.5	0.74

[1]CULTV = cultivated land, BURND = rangeland burned and reseeded to Siberian wheatgrass, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, MNTSG = mountain sagebrush community, ASPEN = aspen community, and CONIF = mixed conifer community.

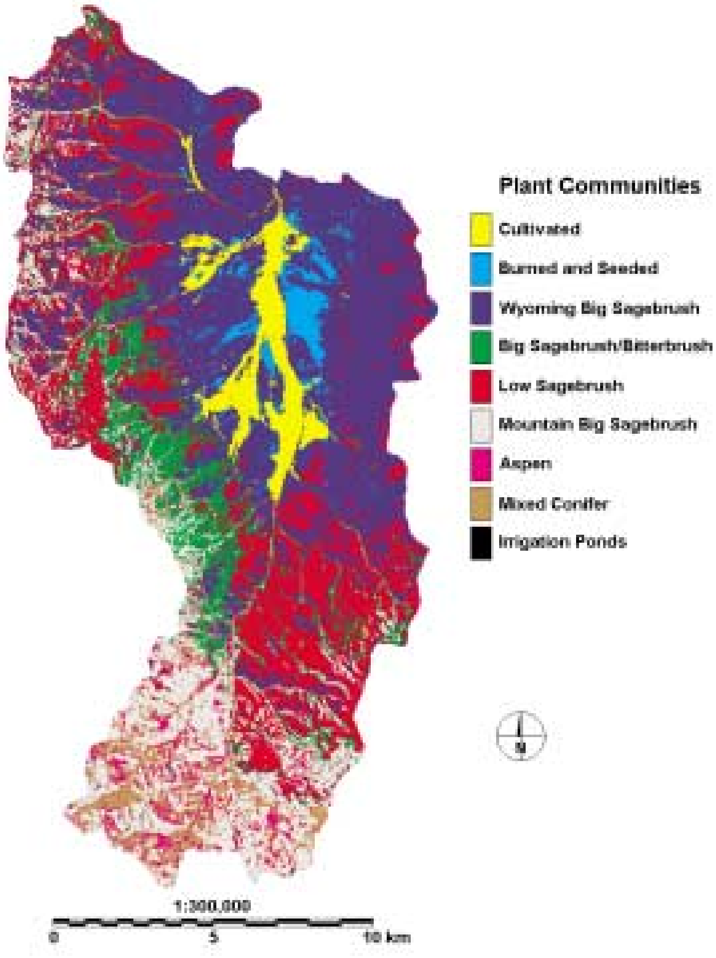

Fig. 5. Plant community map of Reynolds Creek Experimental Watershed in southwestern Idaho created by maximum likelihood classification of a SPOT 3 HRV image acquired 16 August 1994.

areas with more homogenous cover may improve class separability. Improvement of classification accuracy, however, may require combining of poorly separable classes into a single class as was done with the Wyoming big sagebrush and salt desert shrub communities.

Mixed pixels can also contribute to classification error. Mixed pixels are common along distinct patch boundaries. Riparian areas are good examples of where classification errors due to mixed pixels may occur. In arid and semi-arid rangeland there is typically a distinct boundary between low productivity vegetation in the uplands and higher productivity vegetation in the riparian areas. Riparian areas of rangeland streams are typically narrow, often narrower than a Landsat or SPOT image pixel. Imagery of the riparian areas, consequently, will nearly always have pixels which contain spectral information from a combination of both riparian and adjacent upland vegetation. Because of this mixture of spectral information, the classifier may misclassify these pixels to a third class which may be completely out of place both, spatially or ecologically. The presence of spatially-broad ecotones and unclassified intermediate cover types can also result in mapping errors. As in conventional mapping techniques, cover types which grade into each other across a broad area make it difficult to delineate boundary lines.

Practical Considerations

Landsat TM and SPOT HRV scenes acquired in August proved useful for accurately mapping Intermountain plant communities within the Reynold Creek Watershed. Although the probability of obtaining a cloud-free image of Intermountain rangeland is likely better during August than any other month of the year, it still may be difficult to obtain a cloud-free Landsat image during that time period because the 16-day orbit cycle of the Landsat system limits opportunities. If a current-year scene is desired (e.g., to map plant communities following a wildfire), the pointable optics of the SPOT system provide more opportunities to obtain a cloud-free August scene than Landsat. For example, a point at 45° latitude can have as many as 11 viewing opportunities within the 26-day SPOT orbit cycle via off-nadir viewing (Lillesand and Kiefer 1994). Use of SPOT imagery acquired through

Table 5. Maximum Likelihood classifier performance for 8 plant communities in Reynolds Creek Experimental Watershed in southwestern Idaho using Landsat 5 TM multispectral imagery acquired 1 August 1993 based on an accuracy assessment using 240 randomly located reference points.

	Classifier Output (y)								
True Class (x)	CULTV	BURND	WYMSG	SGBIT	LOWSG	MNTSG	ASPEN	CONIF	Total pixels in each true class
CULTV[1]	28[2]					1			29
BURND		25							25
WYMSG	2	3	27						32
SGBIT		1		20		1			22
LOWSG		1	3	6	30	2	4	1	47
MNTSG				4		24	1	3	32
ASPEN						1	24	3	28
CONIF						1	1	23	25
Total pixels in each output class	30	30	30	30	30	30	30	30	240

[1]CULTV = cultivated land, BURND = rangeland burned and reseeded to Siberian wheatgrass, WYMSG = Wyoming big sagebrush community, SGBIT = big sagebrush/bitterbrush community, LOWSG = low sagebrush community, MNTSG = mountain big sagebrush community, ASPEN = aspen community, and CONIF = mixed conifer community.
[2]Each entry indicates the number of pixels the classifier has placed in each respective class y, when in fact they belong to true class x.

off-nadir viewing, however, increases the complexity and potential for problems in image correction and calibration (Royer et al. 1985, Gerstl and Simmer 1986, Moran et al. 1990, Franklin and Giles 1995) and may decrease classification accuracy (Foody 1988).

Landsat data may be more economical than SPOT for resource management applications, particularly for U.S. federal agencies. Landsat scenes are much larger than SPOT scenes (31,450 km^2 compared 3,600 km^2, respectively), thus, an area of interest is more likely to be completely covered on a single Landsat scene than on a single SPOT scene. At the time of this writing, systematic-, precision-, and terrain-corrected SPOT scenes were available from SPOT Image Corp. (Reston, Virg.). System-, precision-, and terrain-corrected Landsat scenes were commercially available from Space Imaging Corp. (Thornton, Colorado) and cost less per km^2 than comparable SPOT scenes. System-corrected Landsat scenes acquired prior to or on 28 October 1992 could be purchased by the public from USGS Earth Resources Observation Systems (EROS) Data Center (Sioux Falls, S.D,) at substantially lower cost than from the commercial vendor. For U.S. federal agencies only, the USGS EROS Data Center also provided precision- and terrain-corrected Landsat scenes for much lower than the commercial cost.

Landsat 7 ETM+ was launched 15 April 1999 to continue the missions of the highly successful Landsat 4 and 5 TM sensors. Landsat 7 ETM+ samples essentially the same 7 bandwidths as Landsat 4 and 5, however, a panchromatic band product (15 m) was also provided. Landsat 7 ETM+ systematic-, precision-, and terrain-corrected scenes were available to the public from the USGS EROS Data Center in Sioux Fall, S.D. A principle objective of the Landsat 7 project was to provide satellite data products to users at cost, a considerable savings over the commercial price for other current Landsat products.

Conclusions

Although the scope of inference for this study was limited to the Reynolds Creek Experimental Watershed, these results suggest both Landsat 5 TM and SPOT 3 HRV provide multispectral data range managers can use to accurately classify and map plant communities on Intermountain rangelands similar to the Reynolds Creek Watershed. Imagery data acquired during dry-down (early August) will likely produce more accurate plant community maps than data acquired during peak growth (early June). Classification of Landsat or SPOT imagery can be a practical and economic means of mapping extensive areas (e.g., grazing allotments, large ranches, watersheds, parks and preserves, and other resource management units) common to the Intermountain West.

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Supplemental polyethylene glycol influences preferences of goats browsing blackbrush

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Abstract

Supplemental polyethylene glycol (PEG) increases intake of foods high in tannins, but it is not known if PEG affects preference when herbivores forage on a variety of foods that differ in concentrations of macronutrients and tannins. We investigated how macronutrients, tannins, and PEG affected preferences of goats (*Caprus hircus*) for current season's and older growth twigs from the shrub blackbrush (*Coleogyne ramosissima* Torr.). In blackbrush, current season's twigs are higher than older twigs in macronutrients, but goats prefer older twigs because high levels of tannins in current season's twigs decrease preference. We conducted a pen trial and a paddock trial. During the 7-day pen trial, goats were offered current season's twigs and older twigs throughout the day. Eight goats were supplemented with 20 g PEG mixed with 100 g ground alfalfa (*Medicago sativa* L.) pellets, and 8 goats were supplemented with 100 g ground alfalfa pellets. Goats supplemented with PEG ate more current season's twigs than goats that did not receive PEG (P = 0.04). During the 17-day paddock trial, 10 goats were supplemented with 50 g PEG mixed with ground alfalfa/barley (*Hordeum vulgare* L.), and 10 goats were supplemented with ground alfalfa/barley. Goats supplemented with PEG preferred current season's to older twigs, whereas PEG-unsupplemented goats preferred older to current season's twigs (P = 0.0001). Goats had equal preference for juniper (*Juniperus osteosperma* Torr.) trees (P = 0.243). Collectively, our findings show that supplemental PEG can change food preferences.

Key Words: tannins, macronutrients, intake, shrubs

Resumen

El polietilen glicol (PEG) suplementario incrementa el consumo de alimentos con altos contenidos de taninos, pero no se sabe si el PEG afecta la preferencia cuando los herbívoros se alimentan en una variedad de alimentos que difieren en la concentración de macronutrientes y taninos. Investigamos como los macronutrientes, taninos y PEG afectaron la preferencia de las cabras (*Capra hircus*) por el crecimiento del año y el crecimiento viejo de ramas de arbustos de "Blackbrush" (*Coleogyne ramosissima* Torr.). En "Blackbrush", el crecimiento nuevo de las ramas tiene un mayor contenido de macronutreientes que el crecimiento viejo, pero las cabras prefieren el crecimiento viejo debido a que el alto contenido de taninos del crecimiento nuevo disminuye la preferencia. Conducimos un experimento en corral y uno en potrero. Durante los 7 días del ensayo en corral, a través del día, se les ofreció a las cabras remas de crecimiento nuevo y ramas de crecimiento viejo. 8 cabras se suplementaron com 20 g de PEG mezclados con 100 g de pelets de alfalfa (*Medicago sativa* L.) molida y 8 cabras se suplementaron con 100 g de pelets de alfalfa molida. Las cabras suplementadas con PEG comieron mas ramas de crecimiento nuevo que las cabras que no recibieron PEG (P = 0.04). Durante los 17 días del ensayo en el potrero, 10 cabras se suplementaron con 50 g de PEG mezclados con alfalfa/cebada molidas (*Hordeum vulgare* L.) y 10 cabras se suplementaron solo con alfalfa/cebada molidas. Las cabras suplementadas con PEG prefirieron las ramas de crecimiento nuevo sobre las de crecimiento viejo, mientras que las que no se suplementaron con PEG prefirieron las ramas de crecimiento viejo (P = 0.0001). Las cabras tuvieron igual preferencia por árboles de "Juniper" (*Juniperus osteosperma* Torr.). Nuestros hallazgos muestran que el PEG suplementario puede cambiar la preferencia por los alimentos.

Tannins suppress intake by reducing digestibility or causing illness. Tannins bind to cell walls and cell solubles (Kumar and Vaithiyanathan 1990, Reed 1995), and in the process reduce digestion of protein and energy-rich volatile fatty acids (Robbins et al. 1987, Makkar et al. 1995). This in turn adversely affects preference (Villalba and Provenza 1996, 1997a, 1997b, 1997c, 1999). Tannins also produce aversive postingestive effects that are best accounted for by lesions of gut mucosa and toxicity (Kumar and Singh 1984, Provenza et al. 1990, 1994, Reed 1995). Supplemental polyethylene glycol (PEG) binds to tannins, and increases intake of high-tannin foods by sheep (Barry 1985, Pritchard et al. 1988, Silanikove et al. 1994, Gilboa 1995), goats (Silanikove et al. 1996), and cattle (Hannigan and McNeill 1998). Despite these promising results, it is not known if PEG changes food preferences when animals eat a variety of foods that differ in concentrations of macronutrients and tannins. We investigated how macronutrients, tannins, and PEG affected preference for current season's and older growth twigs of the shrub blackbrush (*Coleogyne ramosissima* Torr.) by goats (*Caprus hircus*). In

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blackbrush, current season's twigs are higher than older twigs in macronutrients, but goats prefer older to current season's twigs because high levels of tannins decrease goats' preference for current season's twigs (Provenza et al. 1983a, 1983b, 1990, 1994).

Materials and Methods

We conducted a pen trial and a paddock trial. Both studies occurred on blackbrush-dominated land in extreme southwestern Utah at 37.2° N, 113.5°W (for a detailed description of the site see Provenza et al. 1983a, 1983b). The elevation of the study site is 1,280 m. The soils are loams underlain by a petrocalcic horizon at roughly 1 m depth. The dominant vegetation is blackbrush with scattered juniper (*Juniperus osteosperma* Torr.) trees.

Pen Trial

The objective of the pen trial was to compare intake of current season's and older twigs by goats supplemented or not with PEG. During October of 1994, we conducted a trial where goats were confined to individual pens (3 m x 3 m) adjacent to one another. Sixteen Spanish goats (adult females 46 kg) were stratified by weight and then randomly assigned to treatments. Eight goats received 20 g PEG mixed with 100 g of ground alfalfa (*Medicago sativa* L.) pellets, and 8 goats received 100 g of ground alfalfa pellets. Every goat ate all of its supplement immediately after it was offered each day. All goats were then fed 300 g each of current season's and older twigs in separate food boxes from 0900 to 1600 hours daily for 7 days; we collected and weighed refusals each evening. Blackbrush was harvested with clippers and then ground to 3 cm segments in a brush shredder.

Paddock Trial

The objective of the paddock trial was to determine the influence of supplemental PEG on preference of goats for current season's and older blackbrush twigs and juniper trees. To provide ample material for the comparison, a 1-ha paddock of blackbrush was clipped with gas-powered hedge trimmers during March of 1997 to stimulate production of current season's twigs. We clipped roughly one-half of the plants. Clipped and unclipped plants were interspersed throughout the paddock. We removed about 10 to 20 cm from the outer canopy of the blackbrush shrubs which were approximately 1 m in height. During the trial, goats had access to current season's twigs, older twigs, juniper trees and limited amounts of dried grasses and forbs that grew underneath blackbrush plants.

Twenty goats (wethers of mixed dairy breeds) were purchased at 4 to 6 weeks of age and reared at the Green Canyon Ecology Center, Logan, Utah during the summer of 1997. Goats foraged on an orchardgrass (*Dactalis glomerata* 0.)-brome (*Bromus inermis* Leyss.) pasture, and they were group-supplemented every day at 0800 hours with ground barley (*Hordeum vulgar*e L., 400 g goat^{-1}). They had access to trace mineral blocks and water ad libitum. Goats (32 kg) were transported to southern Utah for experiments with blackbrush in October of 1997.

Before leaving Logan, goats were separated into 2 groups (10/group) and familiarized with the supplementation procedure. One group received 50 g of ground barley/alfalfa each morning at 0700 hours for several days. The other group was supplemented (100 g goat^{-1}) with a mixture of ground barley/alfalfa and PEG (50% barley/alfalfa, 50% PEG). Although others have successfully used 25 g of PEG as a supplement for animals eating foods high in tannins (Silanikove et al. 1994), we supplemented lambs with 50 g of PEG each morning in order to ensure that animals received enough PEG to attenuate the effects of blackbrush tannin.

From about 0730 to 1700 hours daily for 17 days in October, goats were allowed to forage in the 1-ha paddock. Each evening at about 1700 hours, PEG-supplemented and PEG-unsupplemented goats were herded into separate pens. Each morning at 0700 hours, 10 goats were fed PEG (50 g animal^{-1}) mixed with ground barley and ground alfalfa pellets, while the other 10 goats were given only the ground barley-alfalfa. Ample food boxes were provided so that all goats could ingest supplement, and all supplement was consumed within 30 min. Goats had free access to fresh water and trace mineral blocks while in pens and while foraging in the paddock.

The amount of barley and alfalfa fed was reduced as the trial proceeded in an attempt to determine if barley-alfalfa affected preference for blackbrush twigs (Table 1). The PEG supplemented group was given the same barley-alfalfa mix during periods 1 and 4, whereas the PEG-unsupplemented group did not receive any barley-alfalfa supplement in period 4 (Table 1).

Shortly after being supplemented each morning, goats were released into the paddock and 2 observers recorded the incidence of eating current season's twigs, older twigs, and juniper. We visually scanned and recorded what each goat was eating at 3-minute intervals for 1 hour (Altmann 1974). Each goat had a number painted on its side to enable data collection by the observer. Goats ate avidly throughout the 1-hour period, so we typically recorded 20 observations hour^{-1} of foraging for each goat. Goats were allowed to forage in the paddock from about 0730 hours until 1700 hours daily.

Table 1. Supplement provided per goat during the paddock trial.

Days	No supplemental PEG	Supplemental PEG
1 to 7	200 g alfalfa/barley	200 g alfalfa/barley, 50 g PEG
8 to 11	100 g alfalfa/barley	100 g alfalfa/barley, 50 g PEG
12 to 15	50 g alfalfa/barley	50 g alfalfa/barley, 50 g PEG
16 to 17	0 g alfalfa/barley	200 g alfalfa/barley, 50 g PEG

Statistical Analyses

For the pen and paddock trials, the repeated measures analyses of variance had 2 treatments (PEG-supplemented and PEG-unsupplemented). Goats (n = 8 treatment^{-1} in the pen trial and 10 treatment^{-1} in the paddock trial) were nested within treatments. Plant part (current season's twigs and older twigs in the pen trial; current season's twigs, older twigs, juniper in the paddock trial) was treated as a split-plot in the analyses. Day (n = 7 in the pen trial and 17 in the paddock trial) was the repeated measure. Least significant differences ($LSD_{.05}$) were determined when F-ratios were significant ($P < 0.05$).

Results

Pen Trial

Intake of current season's twigs gradually increased throughout the 7-day trial (day effect P = 0.0001; Fig. 1). As intake increased from days 4 to 7, PEG-supplemented goats ingested more current season's twigs than non-PEG supplemented goats (treatment x food interaction P = 0.040; Fig. 1). Intake of older twigs did not differ between treatments, though there was a consistent tendency for PEG-supplemented goats to eat more older twigs than PEG-unsupplemented goats (P = 0.211; Fig. 1).

Paddock Trial

Goats supplemented with PEG ate more current season's twigs and less older twigs than non-PEG supplemented goats. Preference for current season's twigs by PEG-supplemented goats varied from day-to-day, especially during the first half of the trial; during the latter half of the trial, preference declined and was less variable (treatment x food x day interaction P = 0.0001; Fig. 2). Preference for current season's twigs by PEG-unsupplemented goats was lower during the first 6 days of the trial than on days 7 to 12, and lower again from days 13 to 17 (Fig. 2). Preference for older twigs generally increased throughout the 17-day trial for PEG-supplemented goats, whereas it remained relatively constant for non-PEG supplemented goats (Fig. 2). There was little correlation between amount of supplemental alfalfa/barley offered and preference for current season's and older twigs by goats not supplmented with PEG. However, as the amount of alfalfa/barley supplement offered declined from days 8 to 15, intake of current season's twigs decreased and intake of older twigs increased for PEG-supplemented goats.

Supplemental PEG did not affect use of juniper by goats ((P = 0.243; Fig. 2). Goat use of juniper fluctuated during the first half of the trial, but varied little thereafter.

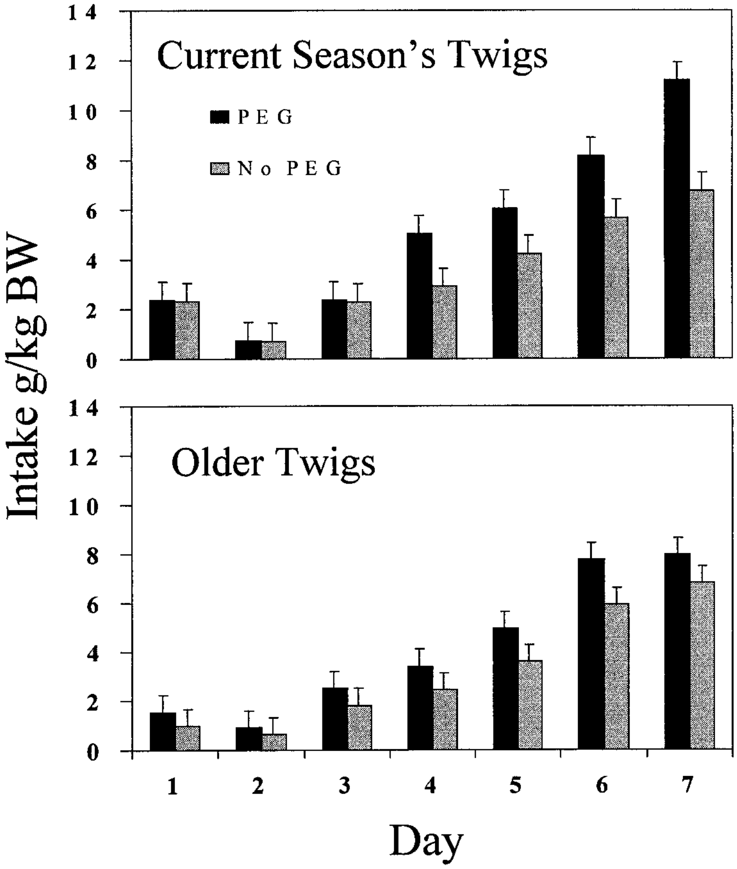

Fig. 1. Intake of current season's and older growth twigs of blackbrush by goats supplemented with 20 g day^{-1} of polyethylene glycol (PEG) plus 100 g ground alfalfa pellets compared with PEG-unsupplemented goats fed only 100 g ground alfalfa pellets (bars represent standard errors; $LSD_{.05}$ = 2.8 for current season's and 2.7 for older twigs).

Discussion

Results from both the pen and the paddock trials suggest that PEG enabled goats to eat more of the nutrient-rich current season's twigs, even though they were higher in tannin than older twigs. The preference by PEG-supplemented goats for current season's rather than older twigs is consistent with the finding that high tannin concentrations in current season's twigs are aversive to goats (Provenza et al. 1990, 1994), and supports the hypothesis that PEG reduced the aversive effects of tannins. Goats in both treatments were naive to blackbrush which accounts for their initially low intakes of current season's twigs and older twigs (Distel and Provenza 1991).

High preferences for current season's twigs by PEG-supplemented goats 1 day were followed by lower preferences the next day during the first half of the paddock trial. Intake of juniper was also cyclical during the first half of the study for both PEG-supplemented and PEG-unsupplemented goats. The daily variation decreased and eventually disappeared, which suggests that goats adjusted intake of current season's twigs to amounts they could tolerate as they became more experienced with both foods (Provenza et al. 1994). Similar cyclical patterns of intake, which occur when cattle ingest tall larkspur (Pfister et. al. 1997), are a result of interactions between the positive postingestive effects of macronutrients and the negative postingestive effects of compounds like alkaloids and tannins (Provenza 1995 1996). Cyclical patterns of preference for current season's twigs also suggest that 50 g of PEG did not completely attenuate the aversive effects of tannin. Depending on the chemical structure and the amount of tannin, higher amounts of PEG may be required to attenuate the effects of various tannins (Provenza et al. 2000).

Intake of current season's twigs by PEG-supplemented goats decreased when we reduced the amount of alfalfa/barley supplement on days 8 to 15, and then began to increase when we again provided supplement on days 16 and 17. This observation is consistent with findings that supplemental macronutrients increase intake of foods high in toxins (Wang and Provenza 1996). Needs for macronutrients increase when animals ingest foods high in toxins (Foley et al. 1995, Illius and Jessop 1995), and additional macronutrients enable animals to ingest more of foods that contain compounds such as terpenes (Banner et al. 2000) and tannins (Villalba, unpublished data).

Though no tests were conducted to elucidate effects of social facilitation on food preferences, we attempted to minimize its effects by trimming blackbrush so that there was complete interspersion of clipped (current season's twigs) and unclipped (older twigs) plants throughout the paddock. Goats supplemented with PEG apparently experienced less aversive postingestive consequences from current season's twigs compared with non-PEG supplemented goats, which would cause

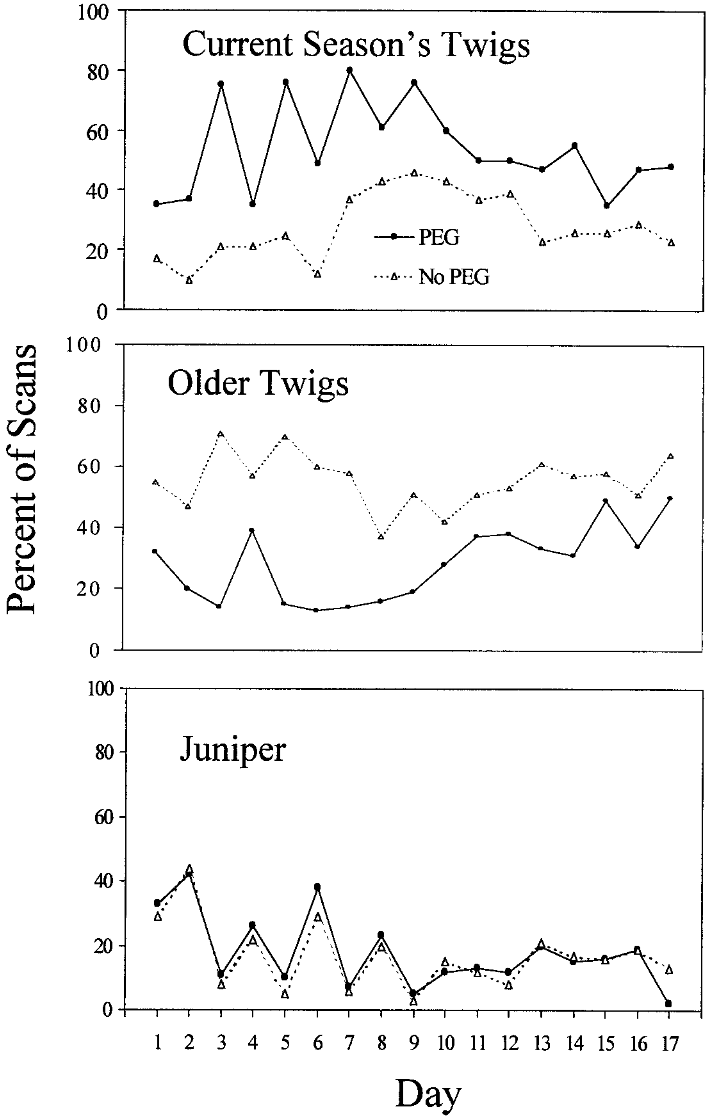

Fig. 2. Frequency of eating current season's and older blackbrush twigs and juniper by goats supplemented with 50 g day^{-1} of polyethylene glycol (PEG) and PEG-unsupplemented (No PEG) goats during the paddock trial (L5D$_{.05}$ = 11).

their food preferences to differ from non-PEG supplemented goats, regardless of the social influences (Provenza et al. 1990, 1994). Lambs, for example, do not continue to eat foods with aversive postingestive consequences (i.e., when they experience toxicosis), even though their mothers avidly eat the foods (Provenza et al. 1993). Social interactions can facilitate behaviors, but continuation of the behaviors depends on the consequence to the individual.

Conclusions

Supplemental PEG might increase preferences of herbivores for tannin-rich forages which could lead to better animal production in areas dominated by tannin-containing species, and allow herbivores to more evenly use rangeland biomass. Supplemental PEG may also enable animals to better maintain fire breaks in areas dominated by plants high in tannins. Our findings are generally consistent with these notions. Results from both the pen and the paddock trials establish that PEG-supplemented goats preferred high-tannin food, whereas PEG-unsupplemented goats did not. While our findings are consistent with the hypothesis that PEG can change food preferences they warrant qualification. The effectiveness of supplemental PEG may be low if alternative forages are equal or superior in nutritional quality and contain less metabolites with aversive effects (Titus et al. 2000). In such cases, animals would likely prefer the alternatives to the high-tannin foods.

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Demographic characteristics of 3 *Artemisia tridentata* Nutt. subspecies

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Abstract

Previous research suggested that woody plant recruitment may occur in pulses in semi-arid areas. The overall objective of this study was to determine if this pulse phenomena was recorded in the demographic structures of big sagebrush (*Artemisia tridentata* Nutt.) stands in Wyoming. In 1997, approximately 75 stem cross sections were collected from 9 stands of each of 3 subspecies of big sagebrush in Wyoming along elevation and climatic gradients. Annual growth-rings were used to identify year of establishment and demographic characteristics were analyzed from age-class frequencies. Mean stand ages of the 3 subspecies were different (P = 0.002), and analyses revealed that Wyoming (*A. tridentata* ssp. *wyomingensis*) and mountain big sagebrush (*A. tridentata* ssp. *vaseyana*) stand ages (32 ± 9 and 26 ± 9 years, respectively) were significantly older than basin big sagebrush (*A. tridentata* ssp. *tridentata*) (17 ± 3) stands (P < 0.05). Mean recruitment intervals (years) were shorter for basin (1.6) than for Wyoming (2.3) and mountain (2.2) sagebrush (P = 0.01). The number of cohorts did not differ among the subspecies (P = 0.11), but the percent of years with recruitment was significantly higher for basin (59%) compared to Wyoming (37%) and mountain (39%) subspecies (P < 0.0001). Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. Chi-square goodness-of-fit tests were performed for the negative binomial distribution. All stands (with one exception) and all 3 regional stand combinations fit the negative binomial distribution. Age-class frequency patterns indicate that recruitment is clustered or aggregated across each period of record. Recruitment in big sagebrush stands occurs in pulses throughout Wyoming.

Resumen

Investigación previa sugiere que en áreas aridas y semiáridos el establecimiento poblaciones de plantas leñosas puede ocurrir en pulsos. El objetivo general de este estudio fue determinar si este fenómeno de pulsos se registro en la estructura demográfica de poblaciones de "Big sagebrush" (*Artemisa tridentata* Nutt.) situadas en Wyoming. En 1997 se colectaron aproximadamente 75 secciones transversales de tallos de 9 poblaciones de cada una de las 3 subespecies de "Big sagebrush" presentes en Wyoming, la colecta se realizó a lo largo de gradientes climáticos y de elevación. Se utilizaron los anillos de crecimiento anual para identificar el año de establecimiento y las características demográficas se analizaron mediante frecuencias de edad-clase. La edad media de las 3 subespecies fue diferente (P = 0.002) y los análisis revelaron que las edades de las poblaciones de las subespecies "Wyoming" (*A. tridentata* ssp. *wyomingenesis*) y "Mountain big sagebrush" (*A. tridentata* ssp. *vaseyana*) (32 ± 9 y 26 ± 9 años, respectivamente) fueron significativamente mayores que la edad de las poblaciones de la subespecie "Basin big sagebrush" (*A. tridentata* ssp. *tridentata*) (17 ± 3) (P < 0.05). Los intervalos de establecimiento (años) fueron mas cortos para la subespecie "Basin big sagebrush" (1.6) que los de las subespecies "Wyoming" (2.3) y "Mountain big sagebrush" (2.2) (P = 0.01). El numero de generaciones no difirió entre subespecies (P = 0.11), pero el porcentaje de años con establecimiento de plantas fue significativamente mayor para la subespecie "Basin big sagebrush" (59%) que el de las subespecies "Wyoming"(37% y "Mountain big sagebrush" (39%) (P = 0.0001). Las distribuciones de frecuencia de edad-clase de cada población y la combinación regional de poblaciones se evaluó para ver la dispersión a través de cada periodo asociado con el registro. Se efectuaron pruebas de bondad de Chi-cuadrada para la distribución binomial negativa. Todas las poblaciones (excepto una) y todas las 3 combinaciones regionales de poblaciones tuvieron un distribución binomial negativa. Los patrones de frecuencia edad-clase indican que el establecimiento es aglomerado o agregado a través de cada periodo de registro. El establecimiento de poblaciones de "Big sagebrush" ocume en pulsos a través de Wyoming.

Key Words: demography, big sagebrush, recruitment intervals

All 3 subspecies of big sagebrush, basin (*Artemisia tridentata* Nutt. ssp. *tridentata*), mountain (*A. tridentata* ssp. *vaseyana* [Rydb.] Beetle), and Wyoming (*A. tridentata* ssp. *wyomingensis* Beetle and Young) characterize many rangeland communities, occupying about 150,800 km^2 of rangelands in Wyoming (Beetle and Johnson 1982). Big sagebrush has a wide ecological amplitude and occupies a diversity of habitats (Beetle 1960), playing crucial roles in reducing erosion, providing wildlife habitat, and improving rangeland aesthetics (Vale 1974).

Distribution is related to elevation, temperature, and soil moisture (Cawker 1980). Wyoming sagebrush occurs at low to mid elevations on fine-textured soils; Basin sagebrush at low to mid elevations but on deep, well-developed soils; and mountain

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sagebrush from mid to high elevations where cooler temperatures, higher precipitation, and developed soils are prevalent (Beetle 1960).

Pulses of recruitment in desert plant communities was suggested by Went (1955) and demonstrated for creosote bush (*Larrea tridentata* [DC.] Cov.) (Chew and Chew 1965, Barbour 1969), for threetip sagebrush (*Artemisia tripartita* Rydb.) and granite pricklygilia (*Leptodactylon pungens* [Torr.] Nutt.) (West et al. 1979). Unusual climatic events and high soil moisture conditions are suggested as major contributing factors (Noy-Meir 1973, Cawker 1980). A pulse is an infrequent recruitment of many individuals into a population. Cawker (1980) demonstrated evidence of climatic control of big sagebrush survival in British Columbia. If rare or infrequent climatic events control pulses of big sagebrush recruitment, these events should be evident within stand age structures as variations in age class frequency. Demography patterns of big sagebrush in Wyoming have not been assessed. Concerns about wildlife species obligate to big sagebrush and declining habitat quantity/quality require a comprehensive understanding of big sagebrush ecology.

This project was conducted to examine the age structure of 9 stands of each of the 3 subspecies on 27 native sites within 3 geographic areas of Wyoming. Specific objectives were to: 1) determine individual and stand ages; 2) compare stand ages, periods of record, number of cohorts, percent of years with recruitment, and recruitment intervals between subspecies; and 3) assess the dispersion of age-class frequencies through time.

Materials and Methods

Mature big sagebrush stands having similar soil characteristics and topography, and minimal herbivory disturbance were selected for this study. Sites were selected to minimize microsite effects that increase or decrease supplemental moisture conditions, thereby minimizing potential variations in recruitment and survival rates between sites (Roughton 1972, Bonham et al. 1991).

Stem sections for *wyomingensis* were collected from 3 stands in northeast Wyoming near Rochelle; 3 stands in the South Fork of the Powder River watershed, northwest of Casper in central Wyoming; and 3 stands in southwest Wyoming near Pinedale. Stem sections for *tridentata* were collected from 3 stands near Pinedale; 3 stands near Worland, on the west slope of the Bighorn Mountains; and 3 stands near Farson, in southwest Wyoming. Stem sections for *vaseyana* were collected from 3 stands near Pinedale; 3 stands near Buffalo, on the east slope of the Bighorn Mountains; and 3 stands west of Laramie, near Elk Mountain in south central Wyoming. The 3 stands in each regional grouping were located within a 15 mile radius. All stand coordinates were determined with a Global Positioning System, and are published in Perryman and Olson (2000).

A stratified, random sampling method was used to collect stem cross-sections from each stand. A permanent 100-m baseline transect was located within each stand, and ten, 100-m perpendicular transects were established at randomly selected points along the baseline transect. Along each perpendicular transect, 8 random points were selected, and the closest individual big sagebrush plant was sampled. If the closest individual was not suitable for accurate age determination (e.g., damaged stem), another random point was selected until a suitable individual was found.

Stem cross-sections were obtained by sawing the plant below ground level (Ferguson 1964) to ensure that the pith and first annual growth ring were included. The stem was then cut approximately 10 cm above the first cut, yielding a 10 cm long stem section. Sampling was conducted during the summer of 1997. Between 75 and 80 stem sections were collected from each stand (Cawker 1980).

In the laboratory, the bottom portion of each stem section was sanded sequentially with 60, 80, 320, and 400 grit sanding belts. Annual growth-rings were examined using a 10 power stereo microscope, and enumerated once by 2 different technicians for a total of 2 observations per sample.

Table 1. Mean and median stand and regional stand combination ages (years) by subspecies, 1997.

Subspecies, Stand, and Regional Combination	Mean	Median	n
wyomingensis			
Stand Rochelle1	28	25	78
Stand Rochelle2	23	19	73
Stand Rochelle3	26	28	73
Northeast WY (Rochell1,2,3 combined)	26	25	224
Stand TT Ranch1	32	33	61
Stand TT Ranch2	30	29	58
Stand TT Ranch3	21	16	59
Southwest WY (TTRanch1,2,3 combined)	27	29	178
Stand Midwest1	45	46	69
Stand Midwest2	50	50	65
Stand Midwest3	39	39	67
Central WY (Midwest1,2,3 combined)	45	46	201
vaseyana			
Stand Elk Mountain1	19	19	67
Stand Elk Mountain2	21	17	69
Stand Elk Mountain3	26	18	69
Southcentral WY (Elk Mountain1,2,3 combined)	22	18	205
Stand East Slope1	23	19	67
Stand East Slope2	15	16	81
Stand East Slope3	17	17	76
Central WY (East Slope1,2,3, combined)	18	17	224
Stand Pinedale1	44	47	60
Stand Pinedale2	34	35	57
Stand Pinedale3	31	25	67
Southwest WY (Pinedale1,2,3 combined)	36	35	184
tridentata			
Stand West Slope1	22	21	76
Stand West Slope2	22	21	70
Stand West Slope3	14	13	78
Central WY (West Slope1,2,3 combined)	19	21	224
Stand Big Sandy1	20	20	70
Stand Big Sandy2	15	14	73
Stand Big Sandy3	14	12	68
Southwest WY[1] (Big Sandy1,2,3 combined)	17	14	211
Stand Big Piney1	14	13	74
Stand Big Piney2	17	17	76
Stand Big Piney3	16	16	72
Southwest WY[2] (Big Piney1,2,3 combined)	16	16	222

[1]West slope of the Green River Basin
[2]East slope of the Green River Basin

Annual growth-rings are formed when the secondary xylem forms concentric rings around the stem during the growing season. Rings are easily distinguished from one another by a distinct cork layer 8-18 cells wide (Ferguson 1964). This layer is produced throughout the growing season between the old and new xylem.

Inter-annual or false rings have not been encountered in big sagebrush at northern latitudes and higher elevations (Diettert 1938, Moss 1940, Ferguson 1964, Perryman and Olson 2000). Location and elevation of sites in Wyoming fulfill both of these criteria. Locally absent rings do occur, however complete absence of rings is almost never encountered due to the unique nature of annual growth-ring formation in big sagebrush (Ferguson 1964, Perryman and Olson 2000).

Many older stems are "lobed" or "rosette" in form and lack radial symmetry. Often the decumbent and decadent form of older stems leads to open pith exposure and deterioration. Accurate age assessments are not possible when the pith is absent. Our sampling was biased for single-stemmed plants with intact piths over individuals without radial symmetry. As a result, some older plants with decadent stems were excluded.

Mean recruitment intervals, periods of record, number of cohorts, and percent of years with recruitment were determined for each subspecies on a statewide scale and assessed with one-way analysis of variance. Multiple comparisons of means were performed using the least significant difference (LSD) test (Saville 1990). Age-class frequency distributions were constructed for each subspecies at 2 geographic scales, stand and regional stand combination. Age-class frequency dispersion through time was assessed by Chi-square goodness-of-fit tests for both Poisson (random) and negative binomial (clustered/aggregated) distributions (Ludwig and Reynolds 1988, Zar 1999). All analyses were determined significant at $P < 0.05$.

Results and Discussion

Individual plants and stands were generally younger than those found in previous big sagebrush dendrochronologic studies (Ferguson 1964, Roughton 1972, Cawker 1980). Prior research indicated that big sagebrush plant age often exceeds 100 years (Blaisdell 1953, Ferguson 1964) in the southwestern U.S. The oldest individual (81 years) in this study was a mountain sagebrush plant located in the Bighorn Mountains. The oldest Wyoming sagebrush plant (75 years) was from the Powder River Basin, and the oldest basin sagebrush plant (55 years) was found near Pinedale, Wyo. Young seedlings, 5–10 years old, were common in all stands. Sampling bias for plants with intact piths may have potentially lowered mean stand ages, however, both younger and older plants were excluded when they lacked intact piths.

Analysis of variance indicated that mean stand ages of the 3 subspecies were differ-

Table 2. Mean recruitment intervals (years), mean number of cohorts in the period of record, mean percent of recruitment years in the period of record, and mean period of record (years) by subspecies sampled across 27 sites in Wyoming, 1997.

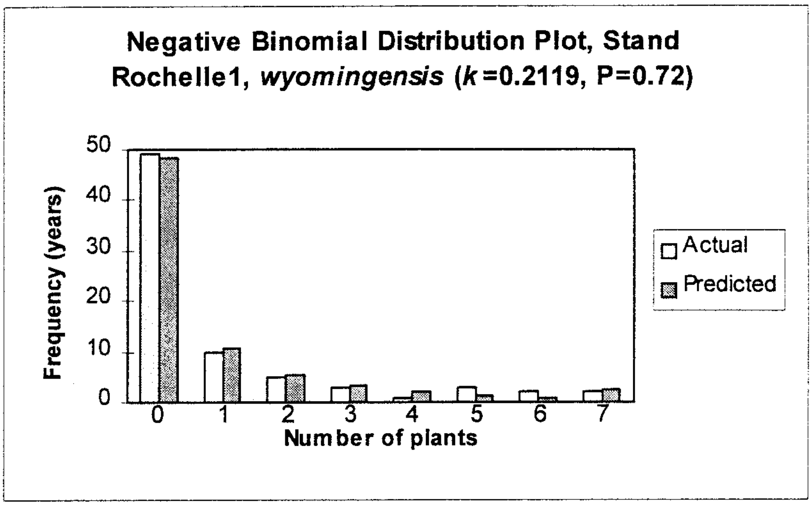
Subspecies	Interval[1]	Cohorts	Recruitment Years	Period of Record
	(YR)	(No.)	(%)	(YR)
wyomingensis	2.3[a] (± 0.7)	23[a] (± 1.9)	37[a] (± 5)	62 (± 6)
vaseyana	2.2[a] (± 0.7)	21[a] (± 4.1)	39[a] (± 6)	54 (± 14)
tridentata	1.6[b] (± 0.6)	20[a] (± 2.4)	59[b] (± 9)	34 (± 8)

[1]Means with the same superscript within a column are not significantly different (P>0.05, LSD).

Table 3. Results of Chi-square goodness-of-fit tests for the negative binomial (p-value and k-exponent value) distribution of individual stands and regional stand combinations, across Wyoming,1997. (Poisson distribution tests were all significant at P < 0.0001).

Stand, and Regional Combination	P-value	k
wyomingensis		
Rochelle1	0.22	0.2387
Rochelle2	0.83	0.2119
Rochelle3	0.64	0.2145
Northeast WY (Rochelle 1,2,3 combined)	0.50	0.2236
TT Ranch1	0.19	0.3612
TT Ranch2	0.23	0.5818
TT Ranch3	0.44	0.3962
Southwest WY (TT Ranch 1,2,3 combined)	0.35	0.5377
Midwest1	0.75	0.2499
Midwest2	0.32	0.3043
Midwest3	0.56	0.3218
Central WY (Midwest 1,2,3 combined)	0.71	0.3667
vaseyana		
Elk Mountain1	0.56	0.4662
Elk Mountain2	0.99	0.3052
Elk Mountain3	0.32	0.2348
Southcentral WY (Elk Mtn. 1,2,3 combined)	0.67	0.2674
East Slope1	0.23	0.3029
East Slope2	0.59	0.1538
East Slope3	0.84	0.2509
Central WY (East Slope 1,2,3 combined)	0.45	0.1659
Pinedale1	0.91	0.2337
Pinedale2	0.81	0.3322
Pinedale3	0.009*	0.3480
Southwest WY (Pinedale 1,2,3 combined)	0.34	0.3698
tridentata		
West Slope1	0.31	0.4497
West Slope2	0.51	0.4889
West Slope3	0.54	0.4069
Central WY (West Slope 1,2,3 combined)	0.11	0.4111
Big Sandy1	0.14	1.2299
Big Sandy2	0.76	0.3408
Big Sandy3	0.68	0.6599
Southwest WY[1] (Big Sandy 1,2,3 combined)	0.31	0.6838
Big Piney1	0.40	0.6382
Big Piney2	0.69	0.4016
Big Piney3	0.79	0.2247
Southwest WY[2] (Big Piney 1,2,3 combined)	0.87	0.2403

[1]West slope of the Green River Basin
[2]East slope of the Green River Basin
*Only stand or stand combination that did not fit the negative binomial distribution.



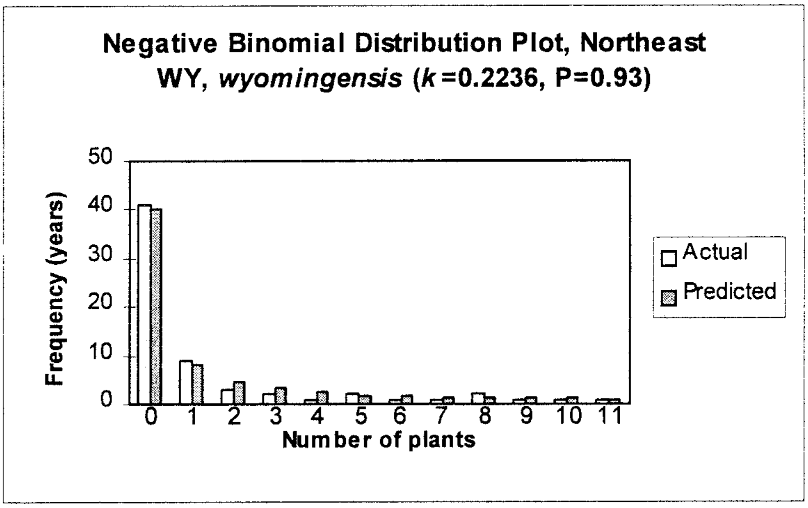


Fig. 1. Negative binomial distribution plots from Chi-square goodness-of-fit tests of (a) a representative stand and (b) a regional combination of stands for Wyoming sagebrush, sampled in northeast Wyoming, 1997.

ent, and the LSD test revealed that Wyoming and mountain sagebrush stands (32, ± 9 and 26, ± 9 years respectively) were older than basin sagebrush (17, ± 3) stands. Mean and median ages for stands and geographic stand combinations by subspecies are listed in Table 1. No difference in stand ages occurred among geographic region (P = 0.60).

Mean recruitment intervals, period of record, number of cohorts, and percent of years with recruitment are in Table 2. Stand recruitment intervals ranged from 1.9 to 2.7 years for Wyoming sagebrush; 1.3 to 2.7 years for basin sagebrush; and 1.2 to 2.9 years for mountain sagebrush. Mean recruitment intervals were shorter for basin sagebrush (1.6 years) than for Wyoming (2.3 years) and mountain (2.2 years) sagebrush. Years with high age-class frequencies occurred at irregular intervals. This supports the hypotheses by Went (1955) and West et al. (1979) that successful recruitment in arid and semi-arid plant communities occurs in pulses, often with many years of no seedling survival between successful years. Shorter intervals reflect more frequent, favorable recruitment conditions and higher rates of seedling survival. Less favorable climatic conditions may lengthen intervals in regions where Wyoming and mountain sagebrush plants occur (West 1978, Cawker 1980).

The number of cohorts did not differ among subspecies, but the percent of successful recruitment years was significantly higher for basin sagebrush (59%) than for the Wyoming (37%) and mountain (39%) subspecies). The shorter mean period of record for basin sagebrush may explain the higher recruitment rate and shorter recruitment intervals. However, big sagebrush recruitment is episodic, and our data suggest that for Wyoming sagebrush, statewide recruitment occurred in only 33 of the past 75 years.

Age-class frequency distributions of each stand and regional stand combination were assessed for dispersion across each associated period of record. No stands or regional stand combinations fit the Poisson distribution ($P < 0.0001$) and all variances were greater than the mean, indicating recruitment is not random, but clustered, aggregated, or contagious (Zar 1999) across a period of record. With the exception of 1 mountain sagebrush stand, all stands and all three regional stand combinations fit the negative binomial distribution. Means were different for each stand and stand combination so *k*-exponent values also differed for each goodness-of-fit test (Table 3).

Cohort or age-class negative binomial distribution patterns were characterized by a relatively large number of years with no recruitment, a moderate number of years with some recruitment, and relatively few years with relatively high recruitment. Graphs of actual frequency probabilities for a representative stand and regional stand combination are displayed in Fig. 1.

Conclusion

We suggest that big sagebrush plants dominating much of the current vertical structure of plant communities in Wyoming are relatively young. However, mean stand ages of Wyoming sagebrush in northeast and central Wyoming are approximately 3 to 4 times older than the mean fire-free interval (8 years) for the area (Perryman and Laycock 2000). Fire suppression activities are often associated with woody plant invasion of northern mixed-grasslands (Kucera 1981, Fisher et al. 1987, Steinaur and Bragg 1987).

Irregular pulses of recruitment are characteristic of big sagebrush stands in Wyoming. These results support hypotheses by Went (1955), West et al. (1979), and Cawker (1980), that recruitment in semi-arid regions occurs in pulses consistent with favorable climate. Other factors such as fire, insect outbreaks, herbivory, and understory composition may also affect demography patterns. However, without favorable weather, recruitment pulses may not occur.

Age-class frequency of big sagebrush stands approximate the negative binomial distribution. Characteristically, there are a large number of years of no recruitment, an intermediate number of years with some recruitment, and a few years of high recruitment. Recruitment intervals are longer for Wyoming and mountain sagebrush than for basin sagebrush. We believe these results reflect general trends of demography in other big sagebrush communities in Wyoming. Our large sample size (approximately 2200 individual plants) and regional consistency of results support our conclusion.

This study describes age-class frequency distributions and pulse recruitment phenomena of big sagebrush in Wyoming. However, future research must address mortality, survivorship curves, and the identification of climatic controls responsible for recruitment pulses of big sagebrush to fully understand the demography of this species.

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Observation: Long-term increases in mesquite canopy cover in a North Texas savanna

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Abstract

It is necessary to quantify rates of woody plant encroachment on southwestern USA rangelands to determine the economic feasibility of treatments designed to manage these plants. This study observed changes in honey mesquite (*Prosopis glandulosa* Torr.) canopy cover over a 20-year period (1976–1995) in 2 treatments: an untreated area that initially had a moderately dense mesquite stand (14.6% cover), and an area cleared of mesquite with root-plowing in 1974. Canopy cover of mesquite was estimated from scanned color-infrared aerial photograph images by manually delineating mesquite canopies with a computer using ArcView software. During the 20 years, mesquite cover in the untreated area increased ($P \leq 0.05$) from 14.6 to 58.7%, averaging 2.2 percentage units per year. Cover in the root-plow treatment also significantly increased during the same period from 0 to 21.9% (1.1 percentage units per year), but the rate of increase was significantly lower than in the untreated area because mesquite growth was from new seedlings instead of established plants and/or new seedlings as occurred in the untreated area. Rate of increase was significantly lower from 1976 to 1990 (1.6 and 0.2 percentage units per year) than from 1990 to 1995 (4.1 and 3.7 percentage units per year) in the untreated and root-plow treatment, respectively. These differences were attributed to precipitation which was near normal from 1976 to 1990 but 25% above normal from 1991 to 1995.

Key Words: honey mesquite, *Prosopis*, density, shrub encroachment, aerial photography, image analysis

Resumen

Cuantificar la tasa de incremento de plantas leñosas en la región del sudoeste de USA es necesario para determinar la factibilidad económica de los tratamientos diseñados para el manejo de estas plantas. En este estudio se observaron cambios en la cobertura de la canopia de mesquite (*Prosopis glandulosa* Torr.) en un período de 20 años (1976–1995) en dos tratamientos: un área no tratada con una cobertura inicial moderadamente densa de mesquite (14.6%), y un área tratada que fue desmontada en 1974 sacando el mesquite desde la raíz. La cobertura de la canopia del mesquite fue estimada a partir de fotografías aéreas digitalizadas color-infrarrojas en las que la canopia se delineó con una computadora que utiliza el programa ArcView. La cobertura de mesquite en el área no tratada se incrementó ($P \leq 0.05$) de 14.6 a 58.7% después de 20 años, con un promedio de 2.2 unidades porcentuales por año. La cobertura en el área tratada también sufrió un incremento significativo desde 0 a 21.9 % en el mismo período (1.1 unidades porcentuales por año). Sin embargo, la tasa de incremento fue significativamente menor que en el área no tratada debido a que el crecimiento del mesquite fue a partir de nuevas plántulas y no de plantas ya establecidas y / o de nuevas plántulas como ocurrió en el área no tratada. La tasa de incremento fue significativamente menor entre 1976 y 1990 (1.6 y 0.2 unidades porcentuales por año) que entre 1990 y 1995 (4.1 y 3.7 unidades porcentuales por año) en las áreas no tratadas y tratadas respectivamente. Las diferencias fueron atribuidas a la precipitación, ya que fue cercana a lo normal desde 1976 a 1990 aunque 25% por encima de lo normal desde 1991 a 1995.

It is necessary to quantify long-term rates of woody plant encroachment on southwestern United States rangelands to determine the economic feasibility of treatments designed to manage such plants. Long-term changes in cover and density of the arborescent legume, honey mesquite (*Prosopis glandulosa* Torr.), on specific sites and soil types are not well quantified (Grover and Musick 1990). Much of the information includes either non-quantitative photographic comparisons (Hastings and Turner 1965, Martin and Turner 1977), summaries of areas either occupied (at any cover or density) or not occupied by mesquite (Buffington and Herbel 1965), or surveys in which mesquite stands are placed into generalized cover classes (e.g., 1–10%) (Smith and Rechenthin 1964, Garrison and McDaniel 1982). Some studies have quantified changes in mesquite cover for specific sites (Parker and Martin 1952, Archer et al. 1988, Warren et al. 1996). However, few data are available for honey mesquite in north Texas or southern Oklahoma, which represent the northern extent of the mesquite distribution range (Fisher et al. 1959, Jacoby and Ansley 1991).

Our objective was to quantify the rate at which honey mesquite increased in canopy cover on a moderately productive clay loam site over a 20-year period (1976 to 1995) using aerial photography. Comparisons were made between a root-plow treatment, which killed over 95% of mesquite and eliminated all mesquite cover, and an adjacent untreated area that initially had a moderately dense stand of mesquite.

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Materials and Methods

Research was conducted on a clay loam site in north Texas, south of Vernon (33° 51'N, 99° 26'W; elevation 381 m). Mean annual rainfall is 66.5 cm. Soils were level and uniform throughout the study area, consisting of fine, mixed, thermic Typic Paleustolls of the Tillman series which are alluvial clay loams 3–4 m deep, underlain by Permian sandstone/shale parent material (Koos et al. 1962). Vegetation was a mixture of native grasses and a mesquite overstory. Lotebush [*Ziziphus obtusifolia* (T.&G.) Gray] comprised less than 2% of the woody species composition. Dominant perennial grasses included Texas wintergrass (*Nasella leucotricha* [Trin. And Rupr.] Pohl.) and buffalograss (*Buchloe dactyloides*) [Nutt.] Englem.).

Changes in mesquite cover were measured on 2 adjacent 3.6 ha (120 m x 300 m) areas which received different treatments: (1) untreated, and (2) root-plowed in 1974 that killed over 95% of mesquite and reduced mesquite cover to zero. The root-plowed area was seeded to sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.] in 1974. Root-plowing followed by seeding were assumed to be 2 phases of the same treatment and are referred to as "root-plow treatment" for the remainder of the paper. Following moderate continuous grazing for at least 50 years, livestock (cattle) grazing was removed from both treatment areas in 1988 (as part of another study).

Both treatment areas were aerial-photographed using color-infrared film in 1976, 1990, and 1995 at low altitude (1:3000 nominal resolution). These photographs were scanned with an approximate 0.1-m resolution using a Microtek Scanmaker E6. Scanned images were georeferenced, using ground control points collected with a GPS unit. Within each treatment, six, 0.2 ha (40 m by 50 m) areas were selected as replicate subsamples along a fixed grid pattern. All 12 subsamples were within 300 m of each other. Mesquite canopies were delineated within each replicate by manually digitizing a line around each canopy on the screen using ArcView GIS (ESRI 1998a). Mesquite canopy cover is synonymous with “aerial crown cover”, and represents the percentage of land surface area occupied by mesquite canopies as viewed from above.

The 1976 images, taken in June, had high contrast between mesquite canopies and grass areas. The 1990 and 1995 images were taken in October of each year and contained considerable shading by canopies which extended into the interstitial spaces between canopies of neighboring trees. Using the digitizing method, we were able to visually exclude most shaded grass areas in the 1990 and 1995 images. About 40 hours were required to hand-digitize mesquite canopies on the 36 plot images (12 per year x 3 sample years; although the root-plow treatment in 1976 had no visible mesquite).

Mesquite cover estimates from the 1990 aerial photographs were compared to line transects performed on the site at the end of the 1991 growing season. In each treatment area, three, 60-meter line transects were established in a fixed grid pattern and mesquite cover was determined using the line intercept method (Cook and Stubbendieck 1986). Additional measurements included mesquite density, determined using the point-centered quarter method, mesquite height, and canopy diameter. Herbaceous composition by percent canopy cover was determined along the same transect lines in October 1994 using a variation of methods outlined by Daubenmire (1959). A 0.25 m^2 frame was placed at each point on the line, and canopy cover of each species as a percent of total ground area within the frame was visually estimated.

Results of digitizing were converted to ArcView Spatial Analyst (ESRI 1998b) grid themes (raster format) with 0.1-m resolution. A landscape analysis software program, FRAGSTATS (McGarigal and Marks 1995), was used to quantify the spatial attributes and temporal dynamics of mesquite canopy patches in the plots (Gustafson 1998, Wu et al. 2000). In addition to the percent cover of mesquite in each plot, the patch density, mean patch size, mean nearest neighbor distance, and mean shape index for the mesquite patches in each plot were determined. A mesquite patch was defined as a discrete area of mesquite canopy consisting of 1 or more individuals with visually connected canopies. Patch density was defined as the number of discrete mesquite areas per ha; mean patch size was the average area of the patches (m^2); and the mean nearest neighbor distance was the average edge-to-edge distance (m) from each patch to its closest neighbor. The mean patch shape index was used to quantify the average shape complexity of the patches in a plot. The shape index of a mesquite patch is defined as $0.25*P/A^{1/2}$, where P is the perimeter and A is the area of the patch (McGarigal and Marks 1995). The shape index equals one for a patch with the simplest raster shape, a square, and increases when the shape of a patch becomes more complex.

The rate of change in percent cover from an earlier year to a later year was determined by subtracting the cover value of the earlier year from that of the later year and dividing this amount by the number of growing seasons between the 2 dates. Annual change was expressed as a “percentage unit” per year when calculated in this manner. The year 1976 was included in rate of change calculations because the photographs were taken at the beginning of the growing season. The years 1990 and 1995 were included in the rate calculations because photographs were taken at the end of each of these growing seasons. Total growing seasons from 1976 to 1995 were 20.

Because the experimental units were not true replicates, t-tests were used to compare the untreated vs. root-plow treatments within each sample year, rate of increase within each treatment, and rate of increase between treatments. All inferences regarding comparisons between treatments were made from individual plots which represent a specific plant community.

Results and Discussion

During the 20-year period from 1976 to 1995, 11 years had above average precipitation and 9 were below average (Fig. 1). Average annual precipitation for all 20 years was 70.3 cm, or 5.7% above normal. Average annual precipitation from 1976 to 1990 was nearly normal at 65.9 cm per year. An extended drought from 1977 to 1981 and record high temperatures in 1980 killed large areas of buffalograss, one of the hardiest grasses in the region (Heitschmidt and Schultz 1985). Annual precipitation from 1991 to 1995 was 25.4% above normal, averaging 83.4 cm per year.

Mesquite canopy cover in the untreated area increased ($P \leq 0.05$) from 14.6 to 58.7% during the 20-year period, an average of 2.2 percentage units per year (Fig. 2). Cover in the root-plow treatment also increased during the same period from 0 to 21.9%, but the rate of increase (1.1 percentage units per year) was significantly lower than in the untreated area. The slower rate in the root-plow treatment was due to mesquite growth only from new seedlings instead of growth from established root systems and/or new seedlings (Hamilton et al. 1981). Cover in the root-plow treatment in 1995 (21.9%) was similar to that in the untreated area in 1976 (14.6%).

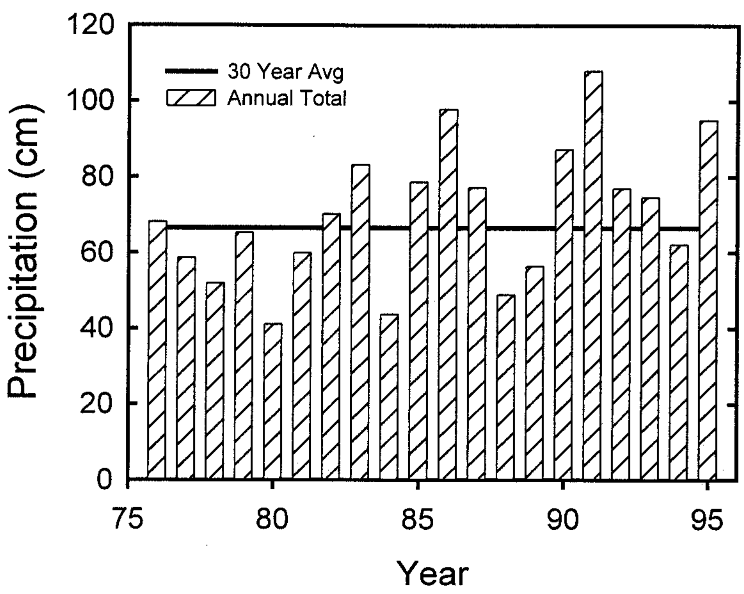

Fig. 1. Annual precipitation at the research site south of Vernon, Texas from 1976 to 1995 compared to the 30-year average.

Rate of increase in both the untreated and root-plow treatments was much lower from 1976 to 1990 (1.6 and 0.2 percentage units per year, respectively) than from 1990 to 1995 (4.1 and 3.7 percentage units per year, respectively). Cover in the root-plow treatment increased at a faster rate from 1990 to 1995 (3.7 percentage units per year) than it did in the untreated area from 1976 to 1990 (1.6 percentage units per year), even though initial cover was less in the root-plow treatment (3.4% in 1990) than it was in the untreated area (14.6% in 1976). This suggests that precipitation had a greater influence on rate of cover increase than did the initial level of canopy cover. It should also be noted that, relative to the 1990 value of 3.4%, mesquite cover in the root-plow treatment increased over 500% from 1990 to 1995 (from 3.4 to 21.9%).

Line transect data indicated that mesquite cover in 1991 was 41.9 (S.E. 8.8) and 14.1 (S.E. 2.8) % in the untreated and root-plow areas, respectively (Fig. 2). In both treatments, the 1991 line transect cover values were greater than that determined from the 1990 aerial images (41.9 vs 38.0 and 14.1 vs. 3.4% in untreated and root-plow treatments, respectively). In the untreated area, if we assume an annual increase in cover of about 2.2%, the 1990 line transect cover value was projected to be 39.7%, which was very similar to the aerial image estimate of 38%. The larger difference between the line transect and aerial image estimates of cover in the root-plow treatment may indicate that the aerial image estimates missed some small plants that were measured by the line transect. In support of this hypothesis, 32% (S.E. 8.8) of mesquite plants measured along line transects in the root-plow treatment had canopy diameters <1 m, compared to 5% (S.E. 0.1) found in the untreated area.

Line transect data also indicated that mesquite density in 1991 was slightly but not significantly greater in the root-plow (470 plants ha^{-1}; S.E. 82) than the untreated area (390 plants ha^{-1}; S.E. 54). Average mesquite height was 3.1 and 1.6 m and canopy diameter was 3.3 and 1.8 m in the untreated and root-plow areas, respectively.

Herbaceous composition by percent cover differed in the 2 treatments due to seeding after root-plowing. In 1994, dominant species in the untreated area were Japanese brome (*Bromus japonicus* Thunb. Ex Murray) (47%), buffalograss (20%) and Texas wintergrass (17%). Dominant species in the root-plow treatment were Texas wintergrass (58%), sideoats grama (21%) and Japanese brome (17%).

Spatial Attributes and Dynamics

In addition to the changes in canopy cover, there had been complex changes in the spatial attributes of mesquite patches which provided additional insights into the dynamics of the systems. Changes in mesquite patch density can be influenced by 3 processes: recruitment of new mesquite plants or patches, coalescing of expanding mesquite patches, and mortality of mesquite trees. In the untreated area, patch density remained unchanged from 1976 to 1990 and then sharply declined from 1990 to 1995 (Fig. 3a). Recruitment of new patches and coalescing of existing patches balanced each other from 1976 to 1990, resulting in stable patch density. The sharp decrease in patch density from 1990 to 1995 indicated considerable coalescing (and possibly decreased recruitment with space and resources becoming more limiting). In the root-plow treatment,

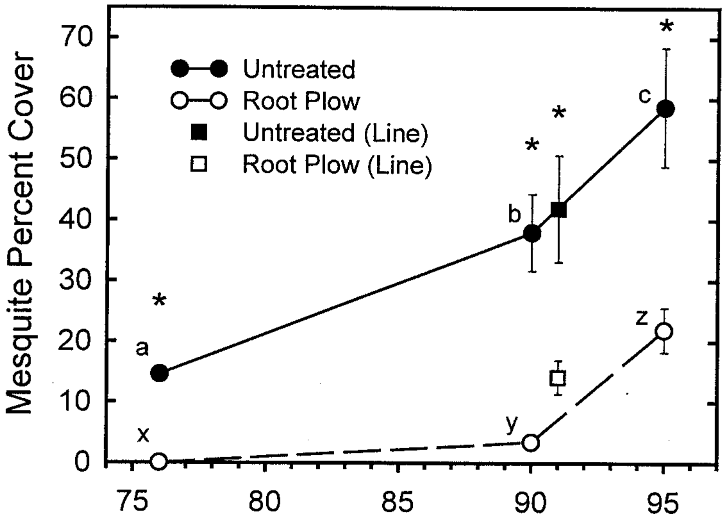

Fig. 2. Mesquite canopy cover in untreated and root-plow treatments near Vernon, Tex. from 1976 to 1995. Circles are aerial image estimates (n = 6) and squares are line transect data (n = 3). Vertical lines indicate ± 1 standard error of the mean. Different lower case letters indicate significant difference (p < 0.05) within a treatment based on t-tests. An asterisk indicates significant difference (p < 0.05) between treatments on a given date.

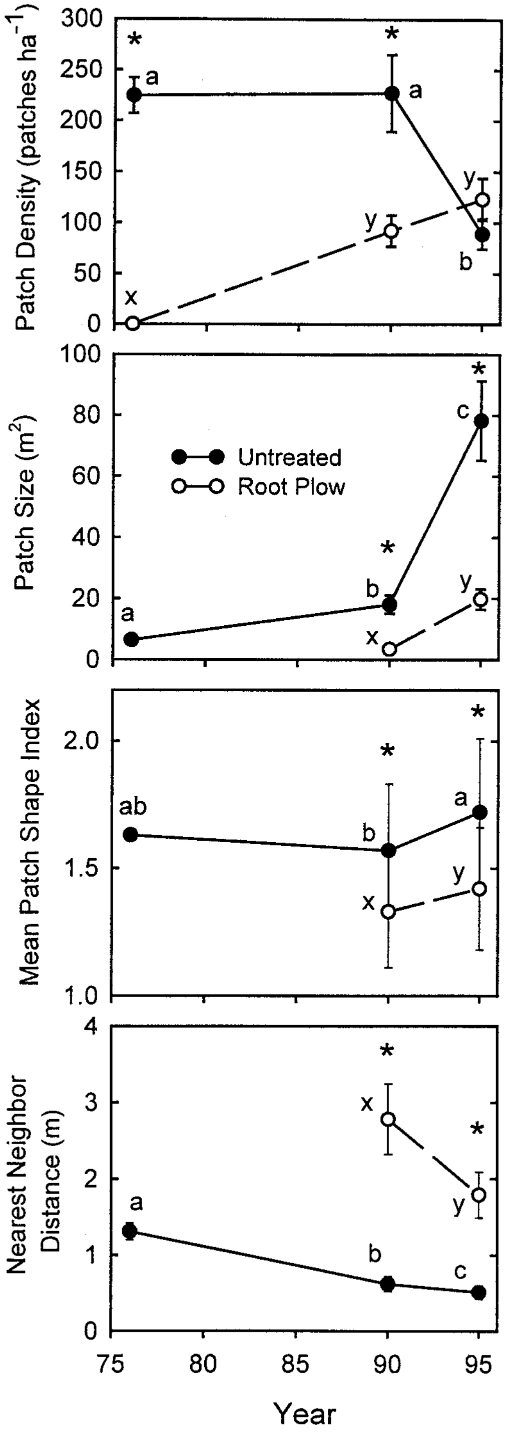

Fig. 3. Spatial attributes of mesquite patches (patch density, mean patch size, mean patch shape index and mean nearest neighbor distance) in untreated and root-plow areas near Vernon, Tex. from 1976 to 1995. Vertical lines indicate ± 1 standard error. Different lower case letters indicate significant difference ($p < 0.05$) within a treatment based on t-tests. An asterisk indicates significant difference ($p < 0.05$) between treatments on a given date.

patch density increased from 1976 to 1995 at a consistent rate. There appeared to be continuous recruitment but little or no coalescing in this period.

Mean patch size in the untreated area gradually increased from 1976 to 1990, followed by a sharp increase from 1990 to 1995 (Fig. 3b). No mortality of adult mesquite was observed at the study site from 1976 to 1995. Patch size increased at a slower rate in the root-plow treatment from 1990 to 1995. The mean patch shape index for the untreated area was similar between 1976 and 1990, then increased significantly from 1990 to 1995 (Fig. 3c). This indicated there was little coalescing or recruitment of new mesquite from 1976 to 1990, because either coalescing (increased shape complexity) or recruitment (more small patches) would change the shape index. Coalescing of expanding mesquite patches from 1990 to 1995 increased the shape index. The shape index was less in the root-plow treatment than in the untreated area in both 1990 and 1995, but increased from 1990 to 1995 due to recruitment (i.e., more small patches).

The nearest neighbor distance in the untreated area decreased from 1976 to 1990 as the mesquite patches grew larger, and the rate of decrease was reduced from 1990 to 1995 by the large amount of coalescing (elimination of many narrow gaps between patches) with little recruitment (Fig. 3d). The greater decline in nearest neighbor distance for the root-plow treatment from 1990 to 1995 suggests a much higher rate of recruitment with lower mesquite cover when compared to the untreated area with higher cover. Change in mesquite cover in 1 of the untreated area replicates is illustrated in Fig. 4. Expansion and coalescing of canopies can be readily observed.

Ecological and Management Implications

Historical accounts differ as to original density and distribution of honey mesquite in north Texas, but observational records indicate the species was present prior to European settlement and, in some instances, occurred as dense stands (Bartlett 1854, Marcy 1866). Increases in mesquite density and distribution during the last century are usually attributed to rangeland management practices which suppressed naturally occurring fires, enhanced seed distribution, and reduced grass competition from livestock grazing (Humphrey 1949, Parker and Martin 1952, Archer 1989, Kramp et al. 1998). Climatic changes and increasing atmospheric carbon dioxide have also been identified as possible reasons for mesquite encroachment (Polley et al. 1994, Archer et al. 1995). Efforts to control mesquite in the last 50 years involved repeated use of chemical or mechanical treatments which often resulted in aboveground mortality (top-kill) but limited whole plant mortality (root-kill) (Jacoby and Ansley 1991). These treatments accelerated increases in mesquite cover because they served to stimulate regrowth from stem bases and an increased number of stems per plant and per land area.

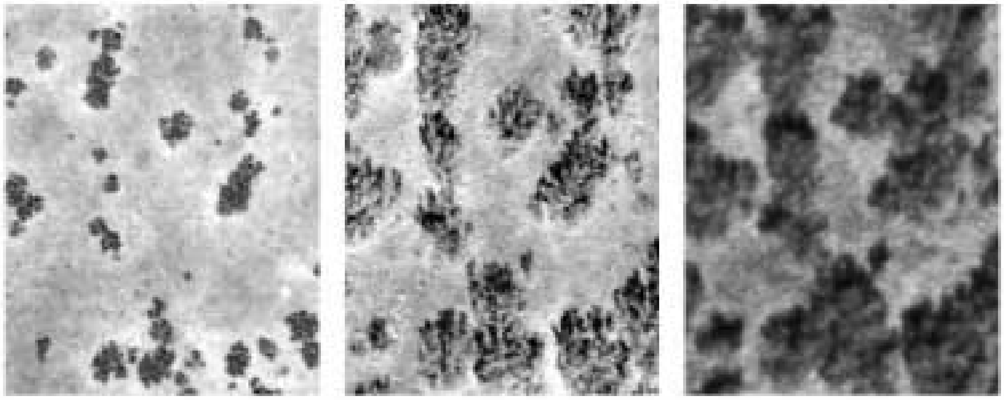

Fig. 4. View of mesquite cover in 1 replicate (40 x 50 m in size) of the untreated area in 1976 (left), 1990 (middle), and 1995 (right). Dark areas on 1990 and 1995 panels indicate shade cast by mesquite canopies. Cover estimates are 11.8, 37.8 and 54.2% in 1976, 1990, and 1995 respectively.

Few studies have examined changes in mesquite cover on specific land areas over time. Usually mesquite encroachment is expressed in terms of changes in distribution (i.e., total area occupied by mesquite), or as a combined distribution/cover index by identifying land areas that have a range of mesquite aerial cover such as 1–10%, 10–20%, and >20% (Garrison and McDaniel 1982, Smith and Rechenthin 1964). For example, Buffington and Herbel (1965) found, on the Jornada Experimental Range in New Mexico, that mesquite-infested areas increased from 11,636 to 36,680 ha from 1858 to 1963, but no data were available on the actual quantitative changes in cover on specific sites. Surveys by the Soil Conservation Service indicated that from 1963 to 1982, the total land area in Texas occupied by mesquite decreased from 22.5 to 20.5 million ha, and areas that had >10% canopy cover decreased from 13.6 to 7.6 million ha (Smith and Rechenthin 1964, SCS 1988). These decreases were probably the result of brush control efforts (Scifres 1980), but no data were available that monitored cover on specific sites through time. Most aerial photographs available from 1940-1980 were taken in winter months when cover of a deciduous plant such as mesquite cannot be clearly delineated. Thus, data which quantifies mesquite cover changes over time are rare.

Of the few long-term studies monitoring mesquite cover on specific sites, rates of increase indicate a range of 0.2 to 1.2 percentage units per year. In south Texas, Archer et al. (1988) determined that mixed brush cover (including mesquite) on two south Texas sites increased from 14 to 23% and 8 to 36%, respectively over 23 years (1960–1983), or 0.4 and 1.2 percentage units per year. However, from 1941 to 1960, a period marked by extreme droughts, cover increased by only 1% on one site (13 to 14%) and declined on the other (13 to 8%). Thus, over a 42-year span (1941 to 1983) cover increases averaged 0.2 and 0.5 percentage units per year, respectively. Warren et al. (1996) determined that honey mesquite cover on two sites in southern New Mexico increased from 1.5 to 8.9% and 5.0 to 16.1%, respectively, over 10 years (1982–1992), an increase of 0.7 and 1.1 percentage units per year. In Arizona, Parker and Martin (1952) found that velvet mesquite (*Prosopis velutina*) cover, when averaged over various grazing treatments, increased from 7 to 17% in 17 years (1932 to 1949), or 0.6 percentage units per year.

Other shrub species in the west or southwest have exhibited slower rates of cover increases. Smeins and Merrill (1988) found that cover of a mixture of woody species in central Texas increased from 12 to 32% over 34 years (1949 to 1983), or 0.6 percentage units per year. Smeins et al. (1994) found in central Texas, that Ashe juniper (*Juniperus ashii* Buchh.) cover increased from 1 to 12% over 30 years (1955 to 1985), or 0.4 percentage units per year. A recent study on 3 sites in Oregon found that increases in western juniper (*Juniperus occidentalis* spp. *occidentalis* Hook.) cover over 42 years (1951 to 1994) ranged from 0.1 to 0.2 percentage units per year (Soule and Knapp 1999). These findings are not surprising because *Juniperus* species have slower growth rates than mesquite (Owens and Ansley 1997).

Differences in reported rates of mesquite cover increases are the results of differences in initial canopy cover, soils, weather, and other factors. However, we can conclude from the data available that long-term increases in mesquite cover rarely exceed 1 percentage unit per year on most sites. In contrast, the 2.2 percentage units per year increase on our untreated area over 20 years was twice that found in the literature. While increases from 1976 to 1990 (1.6 and 0.2 percentage units per year in untreated and root-plowed, respectively) are similar to those of other studies, higher rates of increased cover from 1990 to 1995 (4.1 and 3.7 percentage units per year) seem atypical and suggest either a response to above-normal precipitation or an over-estimate of cover on the 1995 images due to shade cast by mesquite canopies and/or low quality of the images.

Soils on our site are deep clay loams which can annually produce 2,000 to 3,500 Kg ha^{-1} of herbaceous growth in mesquite-free areas. This productive potential is much higher than on sites described by Archer et al. (1988) in south Texas, Warren et al. (1996) in New Mexico, and Parker and Martin (1952) in Arizona. Normal rainfall on our site is also much greater than that in the New Mexico and Arizona studies, but similar to the study site described by Archer et al. (1988) in south Texas. Our results indicate that, even though the growing season is shorter in this northern portion of the mesquite distribution range, rate of mesquite cover increase appears to be no lower than what other studies have determined for more southern mesquite.

Cattle grazing has been associated with increases in the rate of mesquite encroachment either through reduced competition from the herbaceous community (Archer et al. 1995), or through fecal deposition of mesquite seeds (Kramp et al. 1998). The fact that cover increased at a greater rate in both treatment areas after removal of cattle grazing in 1988 cattle grazing did not influence rate of cover increase as much as did precipitation.

As with other woody species, at some high level of cover, mesquite growth may become self-limiting and rate of cover increase may slow. However, there was no indication of this occurring in this study between 1976 and 1995 at cover values as high as 59%. Ansley et al. (1998) found that growth and leaf area of individual mesquite trees was reduced at 40% canopy cover when compared to trees at 12% cover, but effects of these levels of canopy cover on subsequent increases in cover were not determined.

Conclusions

Statistical inferences regarding mesquite cover responses in this study were obtained from individual macroplots within a specific plant community and may not be applicable to other areas. We believe, however, that trends determined in this study are typical of that found on similar community types in north Texas and assume responsibility for these interpretations.

In conclusion, honey mesquite cover increased significantly ($P \leq 0.05$) in both the untreated and root-plow treatments over the 20-year period, but the rate of increase was significantly greater in the untreated area (2.2 percentage units per year) than in the root-plow treatment (1.1 percentage units per year). Rate of increase was greater in both treatments during an above normal precipitation period than during a period which had average precipitation. Rates of increase in cover in the untreated area were greater than that found for honey or velvet mesquite in other studies in south Texas, New Mexico or Arizona. This was attributed to greater annual precipitation and more productive soils at our site. All spatial attributes measured (patch density, patch size, patch shape index, nearest neighbor distance) suggested an increase in coalescence of canopies in the untreated site with little recruitment. Conversely, cover changes in the root-plow treatment were the result of recruitment and growth of individual patches, with little coalescence within 20 years after treatment.

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Relationship between plant species diversity and grassland condition

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Abstract

Although the maintenance of biodiversity has become one of the goals in ecosystem management, the relationships of diversity to ecosystem characteristics such as level of herbivory, productivity, and vegetation structure are still poorly understood. We examined these relationships in 8 native grassland sites differing in grazing histories and range condition in the Mixed Grassland (6), Moist Mixed Grassland (1) and Aspen Parkland (1) ecoregions of southern Saskatchewan. Range condition, assessed using standard methods, ranged from fair to excellent. The Shannon's diversity index followed a curvi-linear relationship with range condition, increasing from fair to good, but decreasing from good to excellent condition, within a range between 0.66 and 2.58. Species evenness was affected by range condition in a similar manner ranging from 0.44 to 0.86. Species richness varied among sites and plots between 4 and 28 plants 0.25 m^{-2}, but changed little with range condition. Most structural parameters, such as the cover, height, or thickness of standing plants (live or dead) and litter, increased with range condition especially from good to excellent. The Shannon's diversity index was positively correlated with forb biomass, but not with biomass of any other group or their combination. Grazing regimes that maintain good range condition also maintain species and structural diversity of grasslands.

Key Words: biomass, litter, sward structure, Saskatchewan, Canonical Correspondence Analysis (CCA), Two-way Indicator Species Analysis (TWINSPAN).

Resumen

Aunque el mantener la biodiversidad ha venido a ser una de las metas del manejo de ecosistemas, las relaciones de diversidad con las características del ecosistema tales como el nivel de herbivoría, productividad y estructura de la vegetación aun son pobremente entendidos. Examinamos estas relaciones en 8 sitios de pastizal nativo de 3 ecoregiones diferentes del sudeste de Saskatechewan, los cuales diferían en el historial de apacentamiento y condición del pastizal, 6 sitios se ubicaron en la ecoregión de pastizal mixto, 1 en la de pastizal mixto húmedo y 1 en la del Parque Aspen. La condición de pastizal, se evaluó por métodos estándar y vario de regular a excelente. El indice de diversidad de Shannon siguió una relación curvilínea incrementando cuando la condición de pastizal paso de regular a buena y disminuyendo cuando paso de buena a excelente, dentro de un rango de 0.66 a 2.58. La uniformidad de especies fue afectada por la condición del pastizal en una manera similar variando de 0.44 a 0.86. La riqueza de especies vario entre sitios y parcelas entre 4 y 28 plantas 0.25 m^{-2}, pero cambio poco con la condición de pastizal. La mayoría de los parámetros estructurales, tales como cobertura, altura, espesura de las plantas en pie (vivas o muertas) y el mantillo aumentaron con la condición del pastizal, especialmente cuando cambio de buena a excelente. El indice de diversidad e Shannon se correlaciono positivamente con la biomasa de hierbas, pero no con ningún otro grupo o sus combinaciones. Los regímenes de apacentamiento que mantienen una condición de pastizal buena también mantienen la diversidad de especies y estructural de los pastizales

Grazing by livestock is often excluded on lands conserved for wildlife in Saskatchewan on the assumption that protection from grazing enhances habitat quality. It has been argued that the total removal of livestock is necessary to restore the health of grassland ecosystems (Fleischner 1994). On the other hand, ungulate grazing is accepted as a key process in many ecosystems, especially grasslands (West 1993), and livestock grazing has widespread influence in natural ecosystems of western North America (Wagner 1978, Crumpacker 1984). Some research indicates that moderately grazed lands can actually be healthier, produce more forage and have less standing dead materials than rangelands where grazing is excluded (G.E. Shuman, Stelljes and Senft 1994, Howitt 1995). Rangelands in good ecological condition support more wildlife than those in excellent condition due to the lack of diversity in plant species and structure in the latter (Smith et al. 1996). Diverse plant communities can be more resistant to disturbances (McNaughton 1985, Tilman and Downing 1994).

The structure, functioning, and species diversity of grassland ecosystems are inter-related (Archer and Smeins 1991, Tilman and Downing 1994) and can be altered by grazing (Huntly 1991). Improper utilization of rangelands by over-grazing can reduce cover and diversity of native plant species (Brady et al. 1989, Cooperrider 1991). Although theoretical models predict that

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moderate grazing may enhance species diversity compared to ungrazed lands (Milchunas et al. 1988), factors influencing biodiversity are still incompletely understood (West 1993, Olff and Ritchie 1998). Experimental data from a wide range of environmental conditions are needed to predict how grazing affects biodiversity in grassland ecosystems. We studied 8 grassland sites across southern Saskatchewan with the objectives: (1) to compare plant species diversity and productivity of ungrazed grasslands with those under light, moderate or heavy grazing, and (2) to evaluate the relationships among plant species diversity, range condition, biomass and sward structure.

Materials and Methods

Site selection

Eight sites in southern Saskatchewan were selected in June 1997 based on their geographical locations, soil characteristics, and grazing regimes (Table 1). One site was located in the Aspen Parkland Ecoregion, 1 in the Moist Mixed Grassland Ecoregion, and the remaining 6 in the Mixed Grassland Ecoregion. All sites were located in the Brown Soil Zone except Estevan which was in the Dark Brown Soil Zone. The soils in both zones are chernozemic. At each site, an ungrazed sub-site was located inside a fenced exclosure; these sub-sites had been protected from domestic grazing from 5 to over 30 years prior to this study. Adjacent sub-sites under light, moderate, and/or heavy grazing also were selected. Estimates of grazing intensity were based on visual inspection and information provided by range managers and ranchers, and were relative to adjacent protected sub-sites. All plots were located on level upland to avoid variations caused by slope and/or aspect. A 1 x 1 m exclosure cage was placed near each plot in the grazed sub-sites to permit measurement of biomass.

Field sampling and data collection

Field sampling was conducted in July and August 1997. Four, 8 x 8 m plots were randomly selected in both protected and grazed sub-sites within the most common plant community at each site. Eight, 0.5 x 0.5 m quadrats were randomly placed in each plot. The percent cover and percent contribution to total shoot biomass of each vascular species were visually estimated. Species in the genus Carex were pooled as Carex sp. except for low sedge (*C. stenophylla* Wahl ssp. *eleocharis* (Bailey) Hulten).

The percent biomass of each species was used to calculate range condition scores (0 to 100%), based on the contribution of climax species to total yield following procedures in Abouguendia (1990). Range condition scores were divided into 4 classes: poor (0 to 24.9%), fair (25 to 49.9%), good (50 to 74.9%), and excellent (75 to 100%). Each class was further divided into 3 equal sub-classes, for example, excellent (-), excellent, and excellent (+).

The percent cover of litter, live clubmoss (*Selaginella densa* Rydb.), dead clubmoss, and bare soil surface within each quadrat were visually estimated. The height of live vegetation and standing dead materials, and thickness of the litter layer also were measured with a ruler. Forbs, grasses, and standing dead materials were clipped and litter was hand-raked from 1 x 1 m quadrats in each plot and put in separate paper bags. Litter was defined as any dead plant materials lying on the soil surface. Harvested materials were oven-dried at 80°C for 48 hours and weighed to give biomass.

Data analysis

Mean percent cover of each species was calculated for each plot. Species richness, evenness, and Shannon Diversity Index for each plot were calculated using PC-ORD (McCune and Mefford 1995). Data on species richness, evenness, diversity index, biomass, and structural parameters were analysed for each site to detect the effect of grazing treatment using a one-

Table 1. Descriptions of 8 grassland sites in southern Saskatchewan.

Site/sub-site	Location	Township	Ecoregion[1]	Utilization
Grasslands National Park	N49°10'W107°30'	Tp2R10W3	Mixed grassland	
NG[2]				Protected for about 5 years
MG				Summer grazing (Jun.-Sep.)
Matador	N50°30'W107°30'	Tp20R13W3	Mixed grassland	
NG				Protected for over 30 years
LG				No or light grazing (Jul.-Sep.) in the last 3 years
Parkbeg	N50°20'W106°10'	Tp18R3W3	Mixed grassland	
NG				Protected for 7 years
HG				Summer grazing (Jun.-Aug.)
Arena	N49°20'W109°05'	Tp5R23W3	Mixed grassland	
NG				Protected for 6 years
MG				Late summer grazing (Aug.-Sep.)
Chaplin	N50°30'W106°40'	Tp17R4W3	Mixed grassland	
NG				Protected for 15 years
HG				Late summer grazing (Aug.-Sep.)
Kerr	N49°55'W105°40'	Tp14R28W2	Mixed grassland	
NG				Protected for 7 years
HG				Late summer grazing (Aug.-Sep.)
Estevan	N49°05'W103°05'	Tp2R5W3	Moist mixed grassland	
NG				Protected for over 10 years
LG				Summer grazing (Jul.-Sep.)
Glenavon	N50°0'W103°00'	Tp13R8W3	Aspen parkland	
NG				Protected for 6 years
MG				Late summer grazing(Jul.-Sep.)
HG				Late summer grazing (Jul.-Sep.)

[1]Based on Padbury and Action 1994.
[2]NG: no grazing, LG: light grazing, MG: moderate grazing, HG: heavy grazing.

way ANOVA; means were separated with LSD (Snedecor and Cochran 1980). Regression analysis was used to compare range condition score with species diversity, biomass and structural parameters, and to compare the Shannon's diversity index with biomass.

Mean cover was used in multivariate analysis with each plot being treated as an individual unit. Species occurring in less than 5% of the plots were eliminated and data were relativized by the overall maximum value before TWINSPAN (Two-way Indicator Species Analysis) for the classification of sites and sub-sites using PC-ORD (McCune and Mefford 1995). Cut levels of 0.00, 0.02, 0.05, 0.10, and 0.20 were used and TWINSPAN terminated at a level with 3 or fewer plots in a group. The mean range condition score of each TWINSPAN group was calculated and the group was named by the most representative sub-site(s). Parameters such as percent cover of live vegetation, litter, live clubmoss, dead clubmoss and bare soil, the height of live vegetation and standing dead materials, the thickness of litter, the biomass of forbs, grass, standing dead materials and litter, as well as range condition score were treated as environmental variables in Canonical Correspondence Analysis (CCA). Both species percent cover and environmental variables were relativized by species or environmental variable maximum, respectively, before CCA. Axis scores were centered and standardized to unit variance and were scaled to optimize the representation of plots (weighted mean scores for species cover). The scores for environmental variables were multiplied by 2 for easy visualization. A joint plot was generated based on the linear combinations of environmental variables and the intraset correlations for environmental variables of Ter Braak (1986).

Results and Discussion

Range condition and species composition as affected by grazing

Range condition in the 17 sub-sites ranged from fair to excellent (+) (Table 2). Range condition scores were significantly reduced by grazing at 3 of the 8 sites. As range condition changed from excellent (+) to good at Chaplin, needle-and-thread (Stipa comata Trin. & Rupr.) remained relatively unchanged, but western porcupine grass (*S. curtiseta* Hitchc.) cover was reduced 7-fold and june grass (*Koeleria gracilis* Pers.) cover increased from 7 to 11%. Northern wheatgrass (*Agropyron dasystachyum* (Hook.) Scribn.) was reduced in cover at Kerr when range condition changed from good to fair, while the cover of moss phlox (*Phlox hoodii* Richardson) and june grass increased. As grazing pressure increased, plains rough fescue (*Festuca hallii* (Vasey) Piper) decreased at Glenavon in the Aspen Parkland Ecoregion. Kentucky blue grass (*Poa pratensis* L.) increased in cover when range condition was reduced from excellent (-) to good (-), but decreased at fair (+) when western wheatgrass (*Agropyron smithii* Rydb.) became dominant.

Even for sites that did not differ significantly in range condition between grazed and ungrazed sub-sites, species composition tended to be modified by grazing (Table 2). The common decreasers included northern wheatgrass, winterfat (*Eurotia lantata* (Pursh) Moq.) and sand grass (*Calamovilfa longifolia* (Hook.) Scribn.), while june grass, western wheat grass, and Kentuchy blue grass were among increasers. Ungrazed sub-sites at Parkbeg and Kerr were not in the highest range condition category, probably because the short protection period was insufficient for full recovery from previous grazing. Some severely disturbed Northern Mixed Prairie sites require decades to reach excellent condition through natural succession (J.F. Dormaar, personal communication).

Plots in the 17 sub-sites were classified into 11 groups of 6 levels by TWINSPAN, based on species composition and cover (Fig. 1). Both species composition and range condition were reflected in the TWINSPAN output. Generally, the geographic location or ecoregion of a site was more important than grazing treatment in determining plant species composition.

Glenavon and Estevan were separated from the rest of the sites by their high cover of Kentucky blue grass, purple milkvetch (*Astragalus danicus* Retz.) and western porcupine grass, and their low cover of low sedge and june grass. Glenavon was separated from Estevan by its higher cover of plains rough fescue and green needle grass (*Stipa viridula* Trin.), typical of the black soil zone, and lower cover of sand grass and dotted blazingstar (*Liatris punctata* Hook.). Heavily grazed Glenavon sub-sites had less plains rough fescue than ungrazed and moderately grazed ones, and western wheatgrass also increased after heavy grazing. Matador differed from Parkbeg, Chaplin, Arena and Kerr by its high cover of yarrow (*Achillea millefolium* L.). Species composition and cover were similar between ungrazed and lightly grazed plots at Matador (even though june grass tended to increase and northern wheatgrass decrease after grazing as shown in Table 2).

Table 2. Dominant species (with percent cover in parentheses) and range condition at 8 grassland sites in southern Saskatchewan. Values are means ± SE of 4 replicates.

Site/sub-site	Dominant species[1]	Range condition	Range condition
Grasslands National Park			
NG[2]	NWG (29), JNG (11), NAT (10)	excellent	81 ± 3
MG	NWG (13), NAT (7), JNG (5)	excellent (–)	79 ± 2
Matador			
NG	NWG (41), JNG (13), WFT (8)	excellent (+)	94 ± 3
LG	NWG (28), JNG (19), WWG (3)	excellent	88 ± 2
Parkbeg			
NG	NAT (37), NWG (17), JNG (10)	good (–)	52 ± 13
HG	NAT (29), JNG (13), NWG (8)	good (–)	50 ± 5
Arena			
NG	NWG (24), NAT (13), PAS (13)	excellent (–)	76 ± 9
MG	NWG (15), NAT (10), WPG (9)	good (+)	71 ± 5
Chaplin			
NG	WPG (43), NAT (7), NWG (5)	excellent (+)	92 ± 3*
HG	JNG (11), NAT (8), WPG (6)	good	64 ± 6
Kerr			
NG	NWG (26), PAS (14), BGR (8)	good	66 ± 3*
HG	PHX (14), PAS (12), JNG (8)	fair	41 ±3
Estevan			
NG	SAG (18), WPG (18), SED (9)	excellent (-)	78 ± 7
LG	WPG (20), KBG (18), NWG (10)	good	67 ± 17
Glenavon			
NG	PRF (49), KBG (6), WPG (6)	excellent (–)	81 ± 6*[3]
MG	KBG (30), PRF (11), WPG (7)	good (–)	53 ± 5
HG	WWG (13), KBG (9), WPG (8)	fair (+)	43 ± 5

[1]BGR, *Bouteloua gracilis*; JNG, *Koeleria gracilis*; KBG, *Poa pratensis*; NAT, *Stipa comata*; NWG, *Agropyron dasystachyum*; PAS, *Artemisia frigida*; PHX, *Phlox hoodii;* PRF, *Festuca hallii*; SAG, *Calamovilfa longifolia*; SED, *Carex* sp.; WFT, *Eurotia lanata*; WPG, *Stipa curtiseta*; WWG, *A. smithii*.
[2]NG: no grazing, LG: light grazing, MG: moderate grazing, HG: heavy grazing.

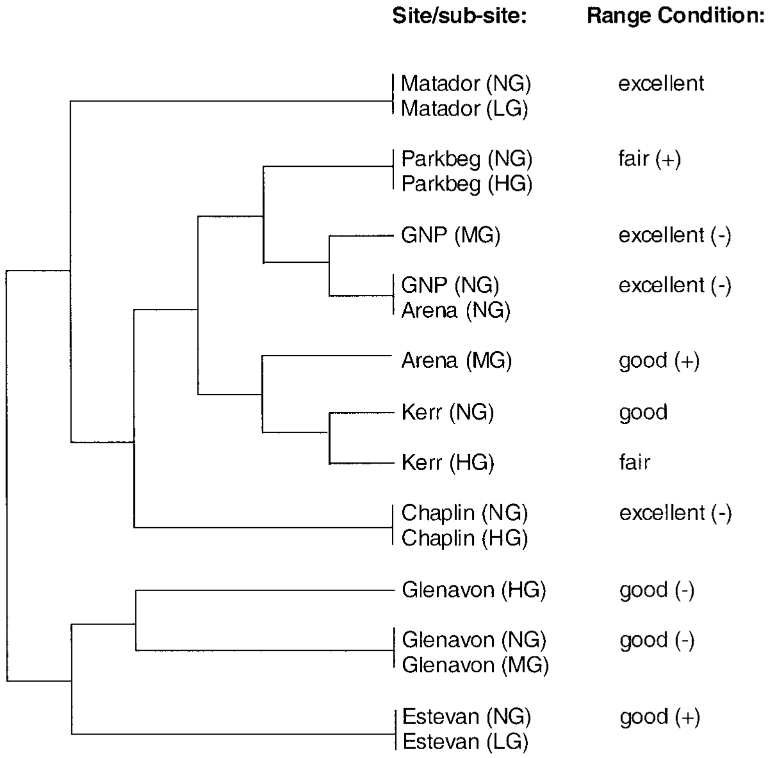

Fig. 1. Classification of grassland sites in southern Saskatchewan based on TWINSPAN and the range condition score for each group. NG: no grazing, LG: light grazing, MG: moderate grazing, HG: heavy grazing, GNP: Grassland National Park.

Chaplin had lower cover of crocus anemone (*Anemone patens* L. var. *wolfgangiana* (bess.) Koch), western porcupine grass, sedges (other than low sedge), and Hooker's oat grass (*Helictotrichon hookeri* (Scribn.) Henr.), but higher june grass, than Parkbeg, Grasslands National Park (GNP), Arena and Kerr.

Parkbeg, GNP and ungrazed Arena sub-sites had higher cover of prairie muhly (*Muhlenbergia cuspidada* (Torr.) Rydb.) and lower moss phlox than Kerr and moderately grazed Arena sub-sites. Parkbeg was separated from GNP and ungrazed Arena sub-sites by its higher cover of june grass and lower cover of pasture sage (*Artemisia frigida* Willd.), northern wheatgrass and moss phlox. There was no difference in species composition for grazed and ungrazed Parkbeg sub-sites; both had low range condition scores. The moderately grazed Arena sub-sites had higher cover of northern wheatgrass and lower sedges (other than low sedge), and spiny ironplant (*Haplopappus spinulosus* (Pursh) DC). Moderately grazed sub-sites at GNP had less cover of white prairie aster (*Aster falcatus* Lindl.) than ungrazed GNP and Arena sub-sites (Fig. 1). Ungrazed Kerr sub-sites had less skeletonweed (*Lygodesmia juncea* (Pursh) D. Don), but higher northern wheatgrass; moss phlox became dominant after heavy grazing.

Relationships between plant species diversity and range condition

The overall average of Shannon's diversity index was 1.69 and 1.95 for ungrazed and grazed sub-sites, respectively. The range of this index was between 0.66 and 2.58 among plots, or between 1.23 and 2.17 among sub-sites. Shannon's diversity index was statistically higher in grazed compared to ungrazed sub-sites at Grasslands National Park (GNP) (2.12 and 1.75, respectively) and Chaplin (2.09 and 1.50, respectively). For other sites, light grazing had little effect on species diversity; the effect of moderate and heavy grazing tended to depend on the difference in range condition between ungrazed and grazed sub-sites. The relationship between Shannon's diversity index and range condition was best described by a quadratic equation (Fig. 2). Plots in good range condition had the highest index. Decreases toward both fair and excellent conditions tend to confirm trends predicted by theoretical models (Milchunas et al. 1988).

The relationship between species evenness and range condition also followed a quadratic equation (Fig. 2). Species evenness for plots in good condition decreased toward both fair and excellent conditions, within a range between 0.56 and 0.78 among sub-sites, or between 0.44 and 0.86 among plots. Grazed sub-sites had slightly higher evenness (0.75) than ungrazed ones (0.65). Grazing did not affect species evenness at individual sites except for Chaplin, where heavy grazing enhanced evenness (0.76 vs 0.56).

The effect of grazing on species richness was not significant at any site, averaging 14 and 16 for ungrazed and grazed sub-sites, respectively. However, species richness varied among sub-sites. The highest species richness was found in moderately grazed Glenavon sub-site (20.8) while the lowest in ungrazed Parkbeg sub-site (7.8). No clear relationship between species richness and range condition was found (Fig. 2). The total number of species, or species richness, did not necessarily reflect shifts in species composition. In other words, even though species compo-

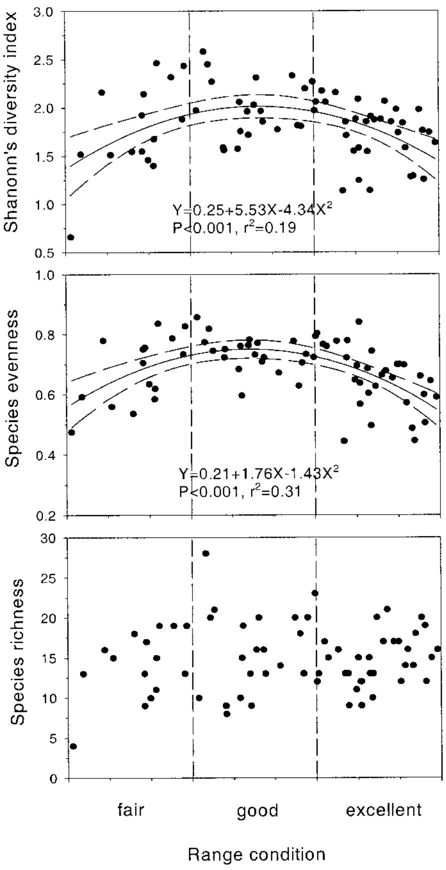

Fig. 2. The Shannon's diversity index, species evenness and richness in relation to range condition of grassland sites in southern Saskatchewan. Data of all plots were pooled. Lines represent regressions and 95% confidence intervals.

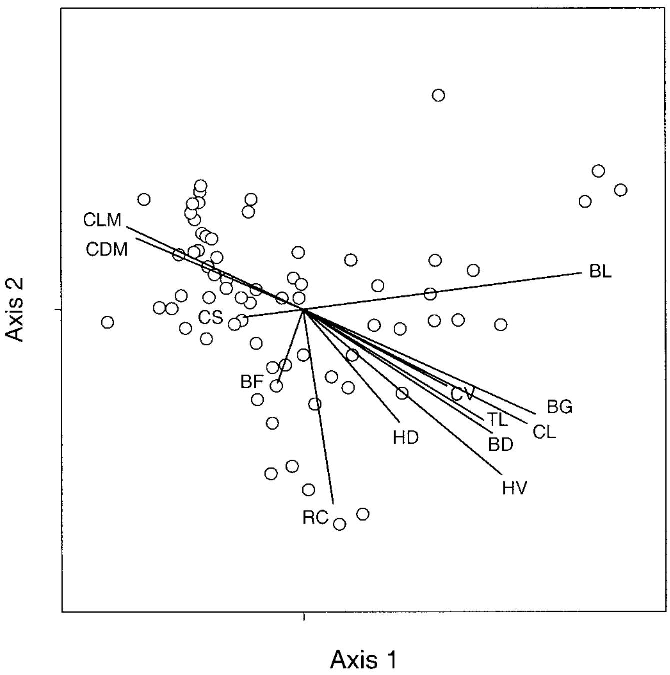

Fig. 3. Joint plot of Canonical Correspondence Analysis (CCA) of grasslands in southern Saskatchewan. Pooled data for all plots. CV: cover of live vegetation, CL: cover of litter, CLM: cover of live clubmoss, CDM: cover of dead clubmoss, CS: cover of bare soil, HV: height of live vegetation, HD: height of standing dead materials, TL: thickness of litter cover, BG: biomass of grass, BF: biomass of forb, BD: biomass of standing dead materials, BL: biomass of litter, RC: range condition score.

sition differs between grazed and ungrazed grasslands, species richness may be similar, as reported in previous studies (Kelt and Valone 1995).

A higher species richness and diversity of grazed plots compared to ungrazed has been reported for tallgrass prairie (Collins 1987, Hartnett et al. 1996), and African grasslands (Smart et al. 1985). High diversity is usually attributed to greater microsite diversity generated by grazing. Other empirical studies have also demonstrated higher species diversity in moderately disturbed than in stable plant communities (Sousa 1980). Plant species diversity can be enhanced by direct consumption of dominant species and indirect effect on competition (McNaughton 1985, Milchunas et al. 1988, Szaro 1989, Huntly 1991, Olff and Ritchie 1998). Savory (1988) suggests that intensive time-controlled, short-duration, planned-rotation grazing will shift rangeland vegetation to more successionally advanced and desirable species. However, this enhanced effect may disappear after heavy grazing due to the shift of species composition to a few dominant species (Davidson 1993, Anderson and Briske 1995). In many rangelands the cumulative effect of long-term grazing is to keep succession in early stages (Longhurst et al. 1982). Variations in the effect of grazing on plant species diversity among sites found in the current study are not surprising because those sites were spread over 3 ecoregions. Species diversity is more likely to be reduced by grazing in stressful environments, such as dry or saline conditions (Milchunas et al. 1988, Olff and Richie 1998), or on poor soils (Ritchie and Olff 1998).

Effect of grazing on sward structure

Heavy grazing reduced the biomass of grasses (Glenavon, Chaplin and Kerr), and favoured that of forbs (Kerr) (Table 3), a trend reported elsewhere (Ten Harkel and Van der Meulen 1996, Watt et al. 1996). Moderate grazing reduced (GNP), or had no influence on grass biomass (Glenavon and Arena); its effect on forbs was not significant at these sites. Light grazing did not affect grass biomass, but reduced forbs in at least 1 site (Matador).

The biomass of standing dead materials and litter also tended to be reduced by grazing (Table 3). Standing dead materials showed a weak, but positive, linear relationship with range condition (Y = 2.1 + 55.9X, P = 0.026, $r^2 = 0.06$), while the relationship between range condition and the biomass of forb, grasses, or litter was less apparent. The biomass of forb exhibited a positive relationship with the

Table 3. Biomass of grass, forb, standing dead materials and litter at 8 sites in southern Saskatchewan. Values are means ± SE of 4 replicates.

Site/sub-site	Grass	Forb	Standing dead	Litter
	- - - - - - - - - - - -	- - - - - - (g/m^2)	- - - - - - - - - - - -	
Grasslands National Park				
NG[1]	60.9 ± 2.7*2	29.6 ± 5.9	17.4 ± 1.2*	27.4 ± 1.2
MG	30.0 ± 2.5	44.7 ±12.7	3.3 ± 0.8	28.0 ± 10.9
Matador				
NG	200.9 ± 30.8	54.3 ± 3.5*	101.3 ± 31.4	139.4 ± 20.6
LG	167.3 ±17.0	31.9 ± 4.6	66.3 ± 6.7	102.4 ± 18.6
Glenavon				
NG	233.8 ± 12.8*	25.9 ± 9.0	121.9 ± 37.7*	612.9 ± 78.6*
MG	192.9 ± 13.9	42.7 ± 4.4	37.1 ± 5.1	206.9 ± 35.2
HG	124.1 ± 27.0	49.5 ± 13.3	32.0 ±16.0	113.4 ± 65.2
Estevan				
NG	151.2 ± 5.6	22.0 ± 12.3	92.1 ± 8.4*	254.1 ± 34.4
LG	144.0 ±7.3	23.2 ± 4.2		52.0 ± 7.3
219.6 ± 33.0				
Parkbeg				
NG	51.8 ± 4.6	8.8 ± 2.8	45.8 ± 5.7	104.6 ± 14.1*
HG	42.9 ± 3.3	10.8 ± 4.5	34.0 ± 8.2	27.4 ± 3.1
Arena				
NG	55.6 ± 3.3	37.9 ± 6.4	11.8 ± 0.9*	30.8 ± 1.9
MG	61.5 ± 4.6	32.2 ± 8.0	7.4 ± 0.7	31.7 ± 4.5
Chaplin	NG	111.4 ±10.3*	25.7 ± 7.3	30.5 ± 4.9*
94.4 ± 25.6*				
HG	28.6 ± 8.5	30.5 ± 6.4	5.5 ± 1.0	25.3 ± 5.6
Kerr				
NG	99.6 ±13.6*	37.1 ± 4.3*	29.7 ± 8.0	110.0 ± 18.3*
HG	38.0 ± 3.1	50.7 ± 1.9	5.4 ± 2.4	11.9 ± 2.2

[1]NG: no grazing, LG: light grazing, MG: moderate grazing, HG: heavy grazing.
[2]*indicates a significant difference between ungrazed and grazed sub-sites (P ≤ 0.05).

Table 4. Structural characteristics of 8 grassland sites in southern Saskatchewan. Values are mean ± SE of 4 replicates.

	Height or thickness			Cover				
Site/sub-site	Live vegetation	Standing dead	Litter	Live vegetation	Litter	Live clubmoss	Dead clubmoss	Bare soil
	(cm)			(%)				
Grasslands National Park								
NG[1]	35.6 ± 1.8*[2]	18.6 ± 0.5*	4.0 ± 0.4*	70.1 ± 0.9*	16.9 ± 2.8	18.0±.0	20.4 ± 3.8*	0.6 ± 3.6
MG	25.3 ± 0.5	8.9 ± 0.2	1.5 ± 0.3	45.8 ± 5.4	12.5 ± 2.3	12.0 ± 2.6	36.7 ± 5.5	3.6 ± 1.5
Matador								
NG	43.7 ± 3.0	27.8 ± 1.8*	8.8 ± 0.4*	82.0 ± 6.3	89.5 ± 2.3*	0	0	0.9 ± 0.5*
LG	39.0 ± 1.1	21.7 ± 0.6	6.8 ± 0.2	71.3 ± 3.5	81.3 ± 1.4	0	0	8.2 ± 1.5
Glenavon								
NG	48.9 ± 2.8*	27.2 ± 1.5*	11.9 ± 0.7*	86.9 ± 1.5	100 ± 0.0*	0	0	0
MG	41.4 ± 3.1	15.0 ± 1.0	3.9 ± 0.8	83.8 ± 3.6	98.0 ± 1.2	0.2 ± 0.2	0	0
HG	24.8 ± 1.9	7.5 ± 1.4	0.9 ± 0.2	69.7 ± 5.3	60.9 ± 7.3	0	0	4.1 ± 0.9
Estevan								
NG	34.9 ± 2.0	30.2 ± 3.7	6.6 ± 1.2	74.7 ± 0.6	94.8 ± 2.1	0.3 ± 0.3	0.1 ± 0.1	0.1 ± 0.1
LG	36.7 ± 1.2	30.5 ± 3.9	9.7 ± 0.6	69.5 ± 5.6	97.3 ± 0.8	1.0 ± 0.7	0	0.1 ± 0.1
Parkbeg								
NG	19.2 ± 1.2*	34.1 ± 0.6	4.3 ± 1.0	74.7 ± 1.7	70.5 ± 6.8	16.0 ± 1.5	25.0 ± 3.7	0
HG	11.3 ± 0.3	26.3 ± 3.4	1.7 ± 0.6	45.9 ± 16	50.5 ± 7.5	20.0 ± 3.7	24.2 ± 5.0	9.4 ± 8.7
Arena								
NG	34.0 ± 1.4*	17.3 ± 0.9*	3.8 ± 0.8*	65.9 ± 3.6	29.7 ± 2.6*	14.1 ± 1.8	31.7 ± 0.9*	1.7 ± 1.7
MG	26.8 ± 1.0	12.6 ± 0.7	0.8 ± 0.2	55.6 ± 3.4	16.4 ± 1.1	15.6 ± 1.4	43.4 ± 2.2	0.3 ± 0.1
Chaplin								
NG	36.1 ± 1.4*	19.3 ± 1.0*	5.7 ± 0.3*	79.4 ± 2.8*	87.3 ± 0.9*	14.2 ± 5.1	33.3 ± 2.8	0.3 ± 0.2
HG	22.9 ± 3.1	11.3 ± 1.5	1.7 ± 0.3	51.1 ± 1.4	33.3 ± 2.1	13.8 ± 1.4	28.0 ± 3.4	1.3 ± 0.6
Kerr								
NG	26.0 ± 0.6*	22.0 ± 0.8*	5.6 ± 0.3*	84.8 ± 3.1*	90.8 ± 2.0*	3.4 ± 2.1	2.0 ± 1.3	0.5 ± 0.2*
HG	15.7 ± 0.7	12.8 ± 0.9	1.3 ± 0.2	56.4 ± 3.1	30.0 ± 4.7	6.5 ± 4.9	4.6 ± 3.4	6.3 ± 1.1

[1]NG: no grazing, LG: light grazing, MG: moderate grazing, HG: heavy grazing.
[2]* indicates a significant difference between ungrazed and grazed sub-sites (P≤ 0.05).

Shannon's diversity index (Y = –14.8 +2 6.0X, P < 0.001, r^2 = 0.26), but that of others such as grass, standing dead material, litter or their combination had weak or no correlation with this index (data not shown). Therefore, results from the current study did not provide evidence that there is a relationship between species diversity and ecosystem stability (measured as biomass) as suggested by Tilman and Downing (1994).

Grazing altered the structure of grassland vegetation. Live vegetation height was reduced both by moderate and heavy grazing, but not by light grazing (Table 4). Total vegetation cover also were reduced by grazing in 3 out of 8 sites, such as GNP (moderate), Chaplin (heavy) and Kerr (heavy). Grazing reduced the height of standing dead materials in all sites except Estevan and Parkbeg. Litter cover and accumulation, measured by its thickness, were also reduced by grazing, similar to previous reports (Schulz and Leininger 1990). Clubmoss cover was site dependent, but grazing tended to increase the cover of dead clubmoss in at least 2 moderately grazed sites (GNP and Arena). Bare soil surface also tended to increase with grazing. The total cover of live vegetation, the cover of litter, the height of live vegetation and standing dead materials, and the thickness of litter increased with range condition following linear or quadratic equations (data not shown).

Canonical Correspondence Analysis

The CCA joint plot demonstrated the correlation between species composition and parameters such as cover, height, and biomass by the direction and length of lines radiating from the centroid of the ordination scores (Fig. 3). The CCA shows the main pattern of variation in species composition as accounted for by environmental variables and the plot distribution along each variable in an approximate way (Ter Braak 1986). Sites and sub-sites were separated best by Axes 1 and 2, but not Axis 3, in the CCA. Thus, only scores of Axes 1 and 2 are presented here. Among the variables, the cover of live and dead clubmoss and the cover of bare soil were negatively correlated with the cover, height and biomass of other plant materials. Range condition tended to correlate with those parameters, but the angle between them indicates that some parameters did not reach their maximum in excellent condition, and some relationships were not linear.

Conclusion

Grazing intensity affects plant species diversity, but not species richness, of grasslands in southern Saskatchewan. As the intensity of grazing increases, species diversity tends first to increase and then decrease, but this trend is site-specific. Grazing alters plant species composition, reduces the biomass of grasses and enhances that of forbs. The biomass of standing dead materials and litter is reduced by grazing. Our research results are relevant to the management of grasslands for purposes of protecting plant species diversity, enhancing habitat quality and improving economic returns. Grazing might be appropriate in the management of some wildlife habitats. The diversity of other ecosystem components such as insects, rodents and birds also need to be considered. The challenge remains for wildlife biologists to interpret plant diversity characteristics in relation to wildlife needs for food and cover. Maintaining species diversity should be an important objective of grazing management.

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Cattle treading effects on sediment loss and water infiltration

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Abstract

To quantify effects of forage canopy properties, soil surface relief, and hill slope on the hydrologic properties of the soil in a New Zealand hill land pasture, duplicate plots (15 x 3 m) with 3 canopy heights (6, 20, and 47 mm) were trodden with 0, 4, or 8 mature cows for 40 min on a moderate (15–18°) slope (Trial 1), and similar plots with the low and high canopy heights were trodden by 8 mature cows for 40 min on gentle (8–14°), moderate (15–18°), or moderately steep (20–25°) slopes (Trial 2). Pre- and post-treading measurements included canopy heights; bare soil proportions; soil moisture contents; hoof prints and skids; roughness coefficients, surface water detention storage volumes, and soil clump volumes with a 38-pin contometer; and water infiltration and sediment loss by rainfall simulation. In Trial 1, increasing canopy height resulted in lower ($P < 0.01$) proportions of bare ground, roughness coefficients, soil clump volumes, and sediment losses. Increasing treading damage resulted in higher ($P < 0.05$) post-treading roughness coefficients, proportions of bare ground, hoof print and skid densities, surface water detention volumes, and soil clump volumes. In Trial 2, soil hydrologic properties did not differ between canopy height or hill slope treatments. In the two trials, water infiltration rate was significantly related to the roughness coefficient ($r^2 = 0.31$) and the number of hoof prints ($r^2 = 0.26$). Results imply that a 20-mm canopy height of the forage species common on a New Zealand hill land pasture is adequate to minimize the effects of a short-term treading event on soil water infiltration rate and sediment loss.

Resumen

Para cuantificar los efectos de las propiedades de la copa del forraje, el relieve de la superficie del suelo y la pendiente de la montaña en la propiedades hidrológica del suelo, se establecieron en un potrero de montaña de Nueva Zelanda parcelas (15 x 3 m) duplicadas con tres alturas de copa del forraje (6, 40 y 47 mm) las cuales se pisotearon durante 40 minutos con 0, 4 y 8 vacas maduras en una pendiente moderada (15-18°) (enasyo1). También se establecieron parcelas similares en terrenos con una pendiente suave (8–14°), moderada (15–18°) y moderadamente pronunciada (20–25°) con alturas de copa baja y alta las cuales fueron pisoteadas por 8 vacas maduras durante 40 minutos (ensayo 2). Las variables medidas antes y después de pisotear las parcelas incluyeron: altura de la copa, proporciones de suelo desnudo, contenido de humedad del suelo, huellas de pezuña y resbalones, coeficientes de rugosidad, volúmenes de detención y almacenamiento de agua superficial y volúmenes suelo pisado, medido con un medidor de contorno de 30 agujas, la infiltración de agua y perdida de sedimento determinados mediante simulación de lluvia. En el ensayo 1, el incremento de la altura de la copa resulto en menores ($P < 0.01$) proporciones de suelo desnudo, coeficientes de rugosidad, volúmenes de suelo pisado y perdidas de sedimento. El incremento en el daño por pisoteo resulto en que después del pisoteo se tuvieran mayores ($P< 0.05$) coeficientes de rugosidad, proporciones de suelo desnudo, densidad de huellas de pezuña y resbalones, volúmenes de detención de agua superficial y volúmenes de suelos pisoteado. En el ensayo 2, las propiedades hipológicas del suelo no defirieron entre tratamientos de altura de copa o pendiente de la montaña. En los dos ensayos, la tasa de infiltración del agua se relacionó significativamente con los coeficientes de rugosidad del terreno ($r^2 = 0.31$) y el número de huellas de pezuña ($r^2 = 0.26$). Los resultados indican que una altura de copa de 20 mm de las especies forrajeras comunes en los pastizales de montaña de Nueva Zelanda es adecuada para minimizar los efectos a corto plazo del pisoteo sobre la infiltración del agua en el suelo y la perdida de sedimento.

Key Words: Hoof damage, canopy, erosion, surface roughness, topography

Damage to vegetation and soils by hoof trampling occurs in pastures grazed at high stock densities, particularly when heavy-weight cattle graze on moist soils (Sheath and Boom 1997, Betteridge et al. 1999). The loss of vegetative and litter cover caused by grazing at high stock densities (Warren et al. 1986a, 1986b, Thurow et al. 1988b) allows direct impact of raindrops on soils (Lal and Elliot 1994). Increased soil bulk density resulting from machinery traffic (Voorhies et al. 1989) or trampling (Warren et al. 1986c, 1986d) of moist soils reduces water infiltration into the soil. The combination of these effects increases surface water flow and sediment loss (Thurow et al. 1986, 1988a, Warren et al. 1986a, 1986d).

In addition to reducing soil surface cover and increasing soil bulk density, hoof damage increases surface roughness (Betteridge et al. 1999). Increased surface roughness may reduce water runoff and sediment loss by lowering kinetic energy of surface water and acting as a trap for detached soil particles (Warren et al. 1986a). On moderate and steep slopes, however, the increased kinetic energy in downhill water flow may exceed the

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mitigating effects of shortened slope length and greater trapping capacity of damaged surfaces and, thereby, increase soil erosion.

The objectives of the present experiment were: (1) to quantify the interactive effects of canopy cover, forage density and canopy height, surface roughness, and hill slope on water infiltration and sediment loss on a moist soil in a New Zealand hill country pasture; and (2) to establish the relationships between physical measurements of soil topography, surface configuration, vegetative cover, and forage density on surface water runoff and sediment loss.

These hill country pastures are commonly grazed by sheep and cattle together, or in some integrated rotation, with canopies being reduced from 150~250 mm to 25~40 mm during long winter-spring rotational grazings in which stock remain in a small area of pasture for 24~48 hours.

Materials and Methods

Study Area

The study was conducted at the AgResearch 'Ballantrae' Hill Country Research Station in southern Hawkes Bay, New Zealand (175°50'E, 40°19'S) at an elevation of approximately 170 m. Soils are Kumeroa hill soils classified as Typic Dystrochrepts related to yellow brown earth and yellow grey earth intergrades. These soils are primarily fine sandy loams with a clay content of 18 to 20%, low organic matter content, and low macroporosity formed on a shallow layer of tertiary sandstone, siltstone or mudstone resulting in poor drainage. The study was conducted on an easterly aspect at slopes of 8 to 25°. Normal annual precipitation at the location is 1,200 mm of which 55% falls during winter and spring. Normal mean temperatures are 16.0 and 7.2°C during summer and winter (Lambert et al. 1983) and, therefore, there is little snow or freezing. Plant composition of the site was 25.7% *Agrostis tenuis* Sibth., 16.4% *Lolium* spp., 14.6% *Cynosurus cristorus* L., 14.1% *Anthoxanthum odoratum* L., 12.7% *Holcus lanatus* L., 6.5% *Trifolium repens* L., 1.5% *Poa* spp., and 8.5% other species (Lambrechtsen 1972). Mean pasture density, determined from twenty-seven, 78 cm^2 cores, was 22,500 grass tillers m^{-2} and 1,600 legume tillers m^{-2}; being typical of fine-leaved sheep-grazed pastures in New Zealand. Cattle-only pastures typically have tiller densities ranging between 6000 to 1,000 tiller m^2. The pastures had been grazed by sheep for the preceding 3 years and had been fertilized with phosphorus at 12.5 kg ha^{-1} as rock phosphate. Mean soil moisture was 416 g kg^{-1}.

Design and Treatments

Two blocks containing three, 15 x 9-m plots were fenced to exclude sheep in September 1997. Plots were randomly assigned to 1 of 3 treading treatments; control, moderate, and severe. Each plot was subdivided into three, 15 x 3-m subplots. Subplots were randomly assigned to 1 of 3 canopy height treatments; denuded, 20 mm or 47 mm. Subplots with the denuded treatment were sprayed with glyphosate (isopropylamine salt of N-(phosphonomethyl) glycine) 3 weeks before pre-treading measurements and hand-clipped at ground level 3 days before pre-treading measurements. Subplots with the 20 mm canopy height were clipped at approximately 25 mm, 3 days before pre-treading measurements were taken. Subplots with the 47 mm canopy height were fertilized with urea at 200 kg ha^{-1} (96 kg N ha^{-1}) 3 weeks before pre-treading measurements were taken. Before pre-treading measurements were taken, one, 1 x 0.5-m site with a moderate (15 to 18°) slope within each 15 x 3-m subplot, was identified to measure the effects of canopy height and surface roughness on infiltration rate and sediment loss. To evaluate the effects of hill slope and canopy height on infiltration rate and sediment loss, 1 x 0.5-m sites with gentle (8 to 14°) and moderately steep (20 to 25°) slopes were identified within each subplot with a short or high canopy that were to be severely trodden.

Treading treatments were applied immediately after pre-treading measurements were taken. Plots with moderate or severe treading were established by slowly walking 4 or 8 mature cows (mean weight, 529 kg), respectively, around the 15 x 9-m plots for 40 min to attempt to obtain uniform treading of each plot. Measurement sites were thus trodden to create approximately twice the number of hoof prints in the severe treading plots as those subjected to moderate treading. The range of hoof print damage caused by each treatment was visually representative of winter grazed pastures. Plots with the control treading treatment were not trodden by cattle and, therefore, represented long-term grazing by sheep only. Standing hoof pressure applied by cows, calculated from the cows' mean weight and the contact area of each hoof print, was estimated to be 195 kPa compared to 80 kPa reported for sheep (Willatt and Pullar 1983). These values, however, may underestimate hoof pressure by a walking animal by as much as 100% (Willatt and Pullar 1983).

Measurements

Sward canopy height at each site was determined from the mean of 25 'first hit' sward stick measurements pre-treading. Proportions of bare soil at each measurement site, defined as exposed soil with no litter, were estimated pre- and post-treading from overhead digital photographs taken with a Kodak DC 50 camera (Kodak Co., Rochester, NY)[1] at a high-resolution setting. Images were cropped using Photoenhancer© software (Kodak Co., Rochester, N.Y)[1], and hue and intensity thresholds for bare soil and green forage were established using the 'Define by Color' tool in Sigma ScanPro© version 4 software (Jandel Scientific Software, San Rafael, Calif.) on portions of the pictures where only bare soil or green forage were present. The proportions of bare ground and green forage cover areas were calculated by dividing the number of pixels identified as bare or covered from the hue and intensity thresholds by the total number of pixels present in each picture. Proportions of bare ground calculated by this method were highly correlated (r = 0.91) to estimates made by counting 76 'first hit' pins at each site, using a contometer described below.

Infiltration rate (from the difference in rainfall and runoff) and sediment loss from each 0.5 x 1.0-m site within each canopy height, treading level, and slope treatment were determined with a rainfall simulator (Bowyer-Bower and Burt 1989) pre- and post-treading. Each simulator was positioned with the longer dimension running downhill. The distance from the base of the rainfall simulator to the soil surface ranged from approximately 0.6 m at the uphill end to approximately 1.0 m at the downhill end. A metal shield forced into the soil around the sites prevented surface flow into or out of the site. To collect surface runoff, a smooth soil face was cut across the downhill end of each site to a depth of approximately 10 cm and protected with Versi-foam© pre-treading and petroleum jelly post-treading. The collection tray was placed into the cut face approximately 5 cm from the soil surface, and collected water was transferred by hose to a 4-liter bottle placed approximately 0.6 m downhill. Mean simulated

[1]Reference to any commercial product does not imply an endorsement of the product by AgResearch or Iowa State University over any similar suitable product.

rainfall rates during 90 min were 36.1 ± 9 liter hr^{-1} (7.22 cm h^{-1}). Raindrop speed ranged from 3.1 to 4.3 m $second^{-1}$ (34 to 47% of terminal velocity) at the uphill and downhill ends of the simulator using a table in Laws (1941) at the rainfall rate and the height of simulator used. Volumes of water applied and runoff collected were recorded at 10-min intervals. The area to which water was applied and collected was adjusted by dividing the 0.5-m^2 area of the rainfall simulator by the cosine of the hill's slope. Water infiltration rate was calculated by subtracting the amount of water runoff by the amount of water applied during each 10-min increment. Steady state water infiltration rate was identified as the interval when incremental infiltration rates did not decrease and was achieved within 60 min in all cases. To determine sediment loss, six, 1-liter samples of runoff were taken and composited for the first 60 min of each rainfall simulation. Sediment concentration was determined by oven-drying duplicate 500-ml subsamples at 105°C until dry. Sediment loss was calculated by multiplying sediment concentration by the water runoff rate for the first hour of each simulation.

Gravimetric soil moisture content was determined on duplicate samples collected at a depth of 0 to 7.5 cm from both sides of each site simultaneous to the determination of infiltration rates and sediment loss. Soil moisture was determined by oven-drying samples at 105°C for 48 hours.

Numbers of hoof prints and skids within each site were counted immediately after the treading event.

Surface roughness was quantified post-treading with a 38-pin contometer (Betteridge et al. 1999) with 25-mm spacing between pins along a 0.95-m transect. To measure surface roughness across each 0.5 x 1-m site, a rectangular frame was constructed that enabled measurements to be taken on 21 parallel transects at 25-mm intervals. Pin heights above the support bar of the contometer were measured using digital photographs cropped using Photoenhancer© software (Kodak Co., Rochester, N.Y.)[1] and analyzed for length using the Longest Axis Length option in the measurement tool of Sigma ScanPro© version 4 software (Jandel Scientific Software, San Rafael, Calif.)[1]. Measurements from the contometer were adjusted to be perpendicular to the horizontal to ensure pin heights were not confounded by land slope. This was achieved by adjusting for slopes of both the contometer and the land with the equation:

Standardized pin height,

$$\text{cm} = (P + L/\sin A_c) - (L * \cos A_c * \sin A_s/\cos A_s \quad \textbf{(1)}$$

where:

P = pin height, cm;
L = distance from the lower end of the contometer to the pin measured, cm;
A_c = angle from horizontal of contometer, degrees;
A_s = angle from horizontal of soil surface, degrees.

Surface roughness was defined for each site as a roughness coefficient calculated as the standard deviation of difference of the standardized pin height in millimeters from the 4-cell moving average along the 21 contometer transects (n = 684) at each site. The 4-cell moving average was calculated as the mean of the 4 pins surrounding a given pin. The use of the moving average transformation was made to separate and remove the variance component caused by land contour from that of a treading-induced disturbance (Eltz and Norton 1997).

The 798 pin readings from each site also enabled a 3-dimensional surface contour graph to determine volumes of depressions or clumps. To include hill slope into the contour of the plot, pin height was only corrected for contometer slope with the equation:

Contour pin height,

$$\text{cm} = P * \cos Ac + L * \sin A_c \quad \textbf{(2)}$$

where:

P = pin height, cm;
L = distance from the lower end of the contometer to the pin measured, cm;
A_c = angle from horizontal of contometer, degrees.

Contours were plotted on a contour graph at 15-mm intervals using incremental colors with Sigma ScanPro© version 4 software (Jandel Scientific Software, San Rafael, Calif.)[1]. Depressions, representing detention storage volumes, and clumps were identified as completely enclosed objects on the graph with the same color line as an adjacent contour line below (depression) or above (clump) the object. Volumes of these objects were calculated from the area of each object plus any additional contour area within each object using the trace measurement option of Sigma ScanPro© version 4 software (Jandel Scientific Software, San Rafael, Calif.)[1] and multiplying this total area by 15 mm. Total surface storage and clump volumes of each site were calculated as the sum of the respective volume measurements on each site divided by the plot area covered by the contometer.

Statistical Analyses

The effects of experimental treatments on canopy height, hoof prints or skids, roughness coefficient, detention storage volume, infiltration rate, and sediment loss were analyzed as a split plot model using General Linear Models (GLM) procedure (SAS 1988) with main effects of treading damage tested against the treading damage by block interaction and canopy height and/or hill slope tested against the error mean square. Post-treading soil water content, rainfall rate for each site, and the corresponding pre-treading independent variables were used as covariates, where appropriate, to standardize the data when testing post-treading independent variables. Stepwise multiple regressions were calculated to determine the dependent variables predicting post-treading steady state water infiltration rate, runoff sediment concentration, and total sediment loss from the independent variables of hill slope, canopy height, post-treading soil moisture, bare soil, hoof print and skid densities, detention storage volume, clump volume, and the roughness coefficient (SAS 1988). Variables were included in the model of the stepwise multiple regression only if they were significant at a probability level less than 0.15.

Results

Canopy Height and Cover

Pre-treading canopy heights of moderate slope (15 to 18°) sites were 6 mm on the denuded site and 20 and 47 mm ($P < 0.01$, Table 1) on the other sites. These canopy heights corresponded to herbage least square mean masses of –74, 273, and 922 kg dry matter ha^{-1}, respectively, at about a nominal clipping height of 10 mm.

The proportion of bare ground was far greater ($P < 0.01$) on denuded sites than on sites with greater canopy heights (Table 2). While the mean proportion of bare ground of denuded sites pre- and post-treading was 80.4%, the mean proportion of bare ground in sites with as little as 20-mm canopy was only 10.8%. The proportion of bare ground was greater ($P < 0.01$) after treading treatments were applied with mean increases of 0, 8.0, and 17.6 percentage units on sites with no, moderate, and severe cattle treading. Because the mean increases in the proportions of bare ground in sites with the denuded, 20 mm and 47 mm canopy

Table 1. Least square means of effects of treading damage and canopy height on soil characteristics and hydraulic properties.

	Treading damage(t)[a]												
	Control[b]			Moderate			Severe						
	Canopy height[c]			Canopy height			Canopy height				Significance		
Item	Denuded	20 mm	47 mm	Denuded	20 mm	47 mm	Denuded	20 mm	47 mm	SEM[d]	t	c	t x c
Canopy height, cm	0.5	1.7	4.7	0.8	2.1	4.7	0.5	2.1	4.9	0.37	0.75	< 0.01	0.96
Soil moisture, g kg^{-1}	408	442	423	453	456	423	408	419	415	20.0	0.32	0.23	0.48
Hoof damage, m^{-2}													
Prints	0	0	0	23	22	22	44	35	39	4.65	< 0.01	0.69	0.88
Skids	0	0	0	2	3	2	8	3	5	1.86	0.02	0.21	0.65
Roughness coefficient, mm	3.4	4.5	4.0	8.7	5.8	6.8	12.5	6.4	8.2	1.05	0.04	0.01	0.02
Detention storage volume, ml m^{-2}	60	12	21	890	529	372	1386	436	632	277	0.02	0.12	0.56
Clump volume, ml m^{-2}	10	18	22	202	82	161	898	109	193	51.9	0.03	< 0.01	< 0.01
Infiltration rate, liter m^{-2} h^{-1}	9.0	4.7	4.0	0.2	7.8	8.8	2.6	4.2	9.6	1.7	0.97	0.13	0.05
Sediment concentration, mg liter^{-1}	349	58	114	377	155	269	522	294	129	178	0.45	0.30	0.93
loss, g m^{-2} h^{-1}	28	55	-20	32	0	-12	19	-11	-16	0.1	0.66	0.01	0.02

[a]In this and later tables, control, moderate, and severe treading damage treatments were treaded on by the equivalent of 0, 296, and 592 cows ha^{-1} for 40 min, respectively.
[b]Sheep only.
[c]In this and later tables, denuded, 20 mm, and 47 mm canopy height treatments were created by glyphosphate treatment and clipping, clipping and nitrogen fertilization, respectively, before the initiation of measurements.
[d]Standard error of the mean.
[e]Canopy height was only measured before treading.

heights were 5, 10, and 11 percentage units (P < 0.05), it seems that sites with the higher canopies had a greater potential for loss of ground cover.

Soil moisture contents at the time of rainfall simulations did not differ between canopy cover or treading treatment (Table 1).

Soil Surface Damage

Treading at the equivalent of 296 and 592 cows ha-1 for 40 min resulted in a mean of 22 and 39 hoof prints m^{-2} (P < 0.01) and 2 and 5 hoof skids m^{-2} (P = 0.02, Table 1). Similarly, roughness coefficients, detention storage volume, and clump volume increased (P < 0.05) as stocking density increased. Because roughness coefficients of sites that were trodden at moderate and severe levels were 178 and 226% of those untrodden sites and roughness coefficients were well correlated with hoof print density (r = 0.75), it seems that the roughness coefficient very effectively describes treading damage treatments. Detention storage volume (r = 0.67) and clump volume (r = 0.61) also were correlated with hoof print density, but not as strongly as the roughness coefficient. Because the detention storage and clump volumes were calculated volumes with a degree of extrapolation, whereas the roughness coefficient was calculated from point values, the closer relationship of hoof print density with the roughness coefficient than those of hoof print density with detention storage volume or clump volume is not surprising.

Canopy heights did not affect the density of hoof prints or skids. However, the roughness coefficient and clump volume were greater (P < 0.01) on denuded sites, particularly as the degree of treading increased (treading damage x canopy height, P < 0.05). This result indicates that while the presence of forage on the ground does not prevent hoof prints or skids from occurring, it apparently minimizes the depth to which hooves sink into the soil, effectively changing the ability of the soil to deform at a moderate moisture content. Similar to the roughness coefficient and clump volume, detention storage volume tended (P = 0.12) to be greater on sites with shorter canopies. The greater clump volumes on the severely trodden denuded sites compared to those on the severely trodden sites with canopy heights of 20 and 47 mm, but not on the moderately trodden sites at all canopy heights, suggests a threshold of treading intensity on denuded land, above which the deformation process is activated but below which compaction only is present. Thus, in New Zealand hill country pastures with the high tiller density of the common sodgrass species, a mean canopy height as short as 20 mm seems to be sufficient to minimize the effects of treading on the soil's rough-

Table 2. Least square means of effects of treading and canopy height treatments on the proportion of bare ground before and after treading.

	Treading damage					
	Control		Moderate		Severe	
Canopy height (c)	Pre-tread	Post-tread	Pre-tread	Post-tread	Pre-tread	Post-tread
	(% bare ground)					
Denuded	78.1	78.1	78.8	82.8	77.0	87.8
20 mm	10.7	10.7	3.3	9.9	3.6	26.7
47 mm	0.4	0.4	0.1	13.5	0.2	19.3
SEM[a]	2.24					
Significance	Main effects	Change by treading				
T	0.22	< 0.01				
C	< 0.01	0.05				
t x c	0.85	0.11				

[a]Standard error of the mean.

ness coefficient and detention storage volume and effectively raise the moisture content at which soil will deform. Volumetric soil moisture contents of the soil at all sites were slightly below the lower plastic limit (46% m^3 m^{-3}) of soils at this site prior to treading. At this volumetric soil moisture content, soils should have compressed when trodden rather than deformed (Betteridge et al. 1999), although the validity of the plastic limit value may be questioned in soils with intact plant roots.

Except where there was no cattle treading, infiltration rate was lower on denuded sites (treading damage x canopy, P = 0.05). The reduction in infiltration rate was associated with those sites with greater roughness, detention storage volume, and clump volume caused by hoof action, which is consistent with the hypothesis that damage to soil surface affects surface infiltration properties and the functional characteristics of the surface and soil pores immediately below the soil surface. The presence of a canopy reduces stock treading damage to the soil surface, as measured by lower roughness coefficients, detention storage volumes, and clump volumes resulting in less smearing and blocking of surface pores and possibly less compaction of subsurface macropores preserving the surface infiltration characteristics of the soil. Thus, during a grazing event, surface infiltration rate will be more prone to negative impacts as animals consume the forage to a height less than 20 mm.

Sediment Loss

Mean sediment concentration was extremely variable between treatments and did not differ between treading damage or canopy height treatments. Similar to sediment concentration, sediment loss was not affected by the amount of treading damage. Because of the reduced infiltration rate and, therefore, greater runoff, sediment loss was greater as the canopy became shorter. The exception to this pattern was that the highest sediment loss occurred on the untrodden, 20 mm canopy height treatment, which may have been caused by soil dislodged from the cut soil face above the runoff collector that grossly inflated the estimate of sediment concentration in one block. For the 2 trodden treatments, the difference in sediment loss was much greater between the denuded and 20 mm canopy heights than between the 20 and 47 mm canopy height treatments. Therefore, similar to the measurements of surface roughness, overland sediment loss is minimized in New Zealand hill land pastures with common forage species at canopy heights as low as 20 mm. While there was no difference in sediment loss between sites with a 47 mm canopy height subjected to the 3 levels of treading damage, sediment loss decreased with increasing treading damage on sites with the denuded and 20 mm canopy height treatments (treading damage x canopy height, P = 0.02). This difference may have resulted from the sites with little or moderate treading damage having the longer slope lengths between obstructions, over which water gains erosive energy (Lal and Elliott 1994) and having less surface depressions into which sediment can be trapped. While treading increases the number and area of clumps from which sediment may erode, it also reduces slope lengths and increases the volumes of detention storage that can detain detached soil particles. Increased roughness of the soil surface and greater canopy covers are major contributors to reducing wind erosion in cropped lands (Skidmore et al. 1994). With the exception of the extremely high sediment loss from the untrod 20 mm canopy height treatment, there was a clear trend for sediment loss declining with increasing canopy height. With treading damage, some disturbance of the soil resulted in an increase in sediment loss, but further damage saw a reduction in soil loss. In stepwise multiple regression analysis, the proportion of bare soil (BS), the average slope (AS) within the range of 15 to 18°, and the roughness coefficient (RC) were selected as significant variables to predict sediment concentration by the equation:

Sediment concentration,
mg liter-1= 3.5BS + 176AS - 32RC -2594 (r^2 = 0.67). **(3)**

In stepwise multiple regressions predicting sediment loss, the proportion of bare soil (BS) and the average slope (AS) within the range of 15 to 18° were selected as significant variables by the equation:

Sediment loss,
gm m^{-2} $hour^{-1}$ = 0.1BS + 2.6AS -38.9 (r^2 = 0.63). **(4)**

Slope and Canopy Cover

As designed, canopy height was greater (P < 0.01) in sites with the 47 mm canopy height than in those that were denuded (Table 3). Canopy height, however, did not differ between sites with different slopes. The proportion of bare ground was greater (P = 0.03) in denuded sites than in those with the 47 mm canopies. Canopy height alone did not affect the density of hoof prints or slips, roughness coefficient, detention surface storage volume, or clump volume. However, roughness coefficients and clump volumes were greater (P < 0.05) on the denuded sites, particularly at the medium slope (canopy height x slope, P < 0.05). Slope, however, did not significantly affect the density of hoof prints or skids or detention storage volume. While in the comparison of canopy height and treading damage discussed above, removal of canopy led to greater soil surface damage when experimental treading treatments were applied, this was only seen on the medium slope in the second trial. The lack of greater damage to the denuded sites with the high and low slopes may be related to uneven damage applied as cattle were moved around these subplots, although there were no significant differences in the density of hoof prints and skids. As in the previous analysis, neither infiltration rate nor sediment concentration was impacted by plant cover, and slope had no effect on infiltration rate, sediment concentration, or sediment loss.

In stepwise multiple regressions using data from the canopy height and slope evaluation, the densities of hoof skids (HS), clump volume (CV), hill slope (AS), and canopy height (CH) were selected as significant variables to predict sediment concentration (Eq. 5), hill slope (AS), density of hoof prints (HP), density of hoof skids (HS), and clump volume (CV) to predict sediment loss (Eq. 6), and density of hoof prints (HP) and roughness coefficient (RC) to predict infiltration rate (Eq. 7) by the equations:

Sediment concentration,
mg $liter^{-1}$ = 28.0HS + 0.16CV - 7.0AS - 27.5CH -251.6 (r^2 = 0.97); **(5)**

Sediment loss,
g m^{-2} $hour^{-1}$ = 0.14AS - 0.14HP + 0.4HS + 0.02CV + 2.76 (r^2 = 0.96); **(6)**

and Infiltration rate,
liter m^{-2} $hour^{-1}$ = 0.26HP - 1.53RC + 9.27 (r^2 = 0.53). **(7)**

Discussion

Previous studies have shown that the relationship between water infiltration and sediment loss is complex and dependent on soil, vegetation, and grazing management (Thurow et al. 1986, Warren et al. 1986a, 1986b, 1986c, 1986d). In this study, treading resulted in an increased roughness coefficient, detention storage volume, and clump volume in conjunction

Table 3. Least square means of the effects of canopy height and hill slope on soil characteristics and hydrologic properties.

	Canopy height (c)							Significance		
	Denuded			47 mm						
	Hill slope (s)[a]			Hill Slope						
Item	Low	Medium	High	Low	Medium	High	SEM[b]	c	s	c x s
Canopy height, mm[c]	5.6	4.7	10.3	31.0	51.1	49.5	35.5	< 0.01	0.22	0.22
Soil moisture, g kg^{-1}, [e]	411	412	401	440	407	318	14.0	0.44	0.14	0.26
Hoof damage, m^{-2}, [d]										
Prints	35	43	38	28	40	29	9.4	0.34	0.41	0.92
Skids	2	8	3	3	5	4	4.5	0.83	0.54	0.79
Roughness coefficient, mm[d]	6.6	12.4	7.5	8.0	7.9	6.5	0.56	0.55	0.02	0.05
Detention storage volume, ml m^{-2}, [d]	758	1396	144	1175	552	230	315	0.86	0.11	0.18
Clump volume, ml m^{-2}, [d]	235	898	265	372	185	7	111	0.25	0.03	0.05
Bare ground, %[e]	80.5	87.9	84.3	24.7	18.3	10.7	2.5	0.03	0.29	0.16
Infiltration rate,liter m^{-2} h^{-1}, [e]	6.9	0.9	8.5	2.0	8.3	9.4	2.73	0.65	0.45	0.34
Sediment,[e] concentration,										
mg $liter^{-1}$	234	490	186	228	154	65	103	0.12	0.34	0.49
loss, g m^{-2} h^{-1}	3.8	18.0	5.6	9.0	4.7	2.2	2.4	0.16	0.12	0.12

[a]Low, medium, and high slopes with 8 to 14, 15 to 18, and 20 to 25°.
[b]Standard error of the mean.
[c]Measured before treading.
[d]Measured after treading.
[e]Measured before and after treading with covariate correction based on measurement made before treading.

with greater density of hoof prints and skids. The presence of a canopy as short as 20 mm minimized the change in soil microrelief, measured as roughness coefficient, detention storage volume, clump volume, or bare ground and reduced sediment loss. The very dense vegetative cover of the sodgrass species common to the New Zealand hill country probably compensates for the lack of canopy height in reducing water erosion, compared with less dense but taller canopies found in other environments. Nevertheless, increasing the canopy height to 47 mm gave even greater protection against sediment loss.

In Texas rangeland containing oak motte, bunchgrass, or sodgrass vegetation types and grazed with 3 different systems, Thurow et al. (1986) found that total vegetative cover was positively and soil bulk density was negatively related to water infiltration rate, and total aboveground biomass and bunchgrass cover were positively related to sediment production. In similar pastures grazed with an intensive rotational stocking system at 3 different stocking rates, it was found that vegetative biomass and bare ground percentage were significantly correlated with water infiltration rate and sediment production (Warren et al. 1986c).

The observation that minor surface damage in the absence of a vegetative canopy results in more sediment loss than severe damage is consistent with guidelines for reducing soil loss from wind and water erosion from cropland. A shorter field length reduces the erosiveness of wind (Skidmore et al. 1994) or water (Lal and Elliot 1994), and the consequent rougher surface creates turbulence that reduces the speed of air or water. A rougher surface also entraps moving particles, which are then unable to contribute to abrasive erosion (Lal and Elliot 1994). Vegetative cover dissipates the energy of falling raindrops and the grass tillers and rooted stolons of clover act to reduce the "field length" over which water can run uninterrupted.

In this experiment, the highly variable infiltration rate tended to mask patterns related to cover and roughness. In the untrodden sites, infiltration rate was slower in the sites with 20 and 47 mm canopy heights, possibly because the vegetative cover formed a protective layer, reducing effective rainfall at ground level. In the moderately and severely damaged sites with 20 and 47 mm canopies, infiltration rates were faster than denuded sites although the trodden denuded sites had greater roughness coefficients and tended to have greater detention storage detention volumes. Thus, the slower infiltration rates in trodden denuded sites may have been caused by fine sediments generated during treading and dislodged by water that may have sealed the infiltration sites in the soil surface. Thurow et al. (1986) observed lower water infiltration rates and greater sediment loss from dense sodgrass than from the more open bunchgrass or oak motte vegetations. Whereas the proportion of vegetative cover including litter was between 45 and 70% on the sodgrass sites used by Thurow et al. (1986), the mean postgrazing vegetative covers of the sites with medium and high canopy heights in the present experiment were 84 and 89%.

In spite of the large effects of 'nominal' canopy height on the bare ground percentage, roughness coefficient, and sediment loss, 'actual' canopy height was not related to infiltration rate or sediment loss. The percentage of bare ground and slope (within the 14 to 18° range only) explained 63% of variation in sediment loss and with the roughness coefficient accounted for 67% of variation in sediment concentration. Warren et al. (1986b) confirmed the importance of vegetative cover as they found that animal trampling on sites devoid of vegetation on dry and moist soils resulted in infiltration rate and sediment loss being highly correlated to soil bulk density and microrelief. The positive relationship between bare ground and sediment loss in our first trial likely was caused by both reduced interception of rainfall by plant material and the reduced obstruction of sediment transport. Because of the high density of tillers and stolons, sodgrass species in New Zealand hill country pastures likely require less herbage biomass to achieve the same level of protection against rain afforded by the more open bunchgrass species present in Texas rangeland.

When comparing the effects of canopy height and slope of soil hydrological properties, sediment loss increased with increasing slope, hoof skid density, and clump volume. Surprisingly, the proportion of bare ground was not a significant factor in the prediction of infiltration rate or sediment loss across a greater range of slopes (8 to 25°) in the second trial despite proportions of bare ground of 84 and 18% on the denuded and 47 mm canopy height sites, respectively. The lack of differences in infiltration rate and sediment loss may have been caused by collecting these data from only severely damaged sites on which variation in sediment loss was low. The negative impact of slope on sediment concentration probably reflects the shorter field lengths between obstructions that reduce water's erosiveness on steeply sloping sites compared to gently sloping ground. At a given plant density, taller canopies negatively impact sediment concentration by reducing the energy of impacting raindrops.

Whereas a rough surface reduces sediment loss by trapping more sediment and reducing water's erosivity, it reduces infiltration rate, probably because of the blocking of surface micropores by trapped fine sediments. The positive relationship between hoof print density and infiltration rate is difficult to explain, as hoof prints are likely associated with either compacted soil under the print when the soil is at a moisture content within the plastic range, or a loss of pore continuity if the soil was deformed by treading in poorly drained hill country soils in New Zealand (Betteridge et al. 1999). While the increasing infiltration rate with hoof print density may have been associated with greater retention volumes, infiltration rates in our study were determined after steady state infiltration was achieved and, therefore, retention structures should have been filled.

Increasing soil microrelief has been negatively related to sediment loss from Texas rangeland (Warren et al. 1986a, 1986b, 1986d, Thurow et al. 1988a). While the increased microrelief in the Texas study was caused primarily by the presence of plant material that would increase water and sediment retention on a low slope, the increased microrelief in the present study occurred primarily in the absence of plant material and was related to hoof damage.

Conclusion

Infiltration rate of soil under New Zealand hill country pastures will be reduced by treading wet pastures, particularly if the postgrazing canopy height is short and the stocking rate is high. A canopy height of only 20 mm is high enough to limit the effects of a short period of treading damage. The lack of a relationship between sediment loss and roughness coefficient supports the finding that soils receiving severe damage in the presence of an adequate canopy are less prone to incipient sediment loss than is the case of less severely damaged soils devoid of vegetation.

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Technical Note: A simple method for preparing reference slides of seed

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Abstract

Microhistological analysis has become the most commonly used and successful method for determining micromammal diets. However, this technique has a number of limitations, particularly when used on fecal samples where identification of some items is difficult. This method underestimates those nearly unrecognizable plant parts in the diet, such as seed, and overestimates easily identifiable parts, such as leaf epidermis. In this note we describe a simple technique that uses a macerating solution of 17.5% $NaHCO_3$ for preparing reference slides of seeds. Advantages of the proposed method are discussed and compared with Jeffrey's technique.

Resumen

El análisis microhistológico ha sido el método más utilizado para determinar la dieta de micromamíferos. Sin embargo, esta técnica tiene importantes limitaciones, principalmente cuando se requiere identificar algunas partes duras de las plantas, como semillas y tallos. Por un lado, ésto ha conducido a que se subestimen las partes dificilmente identificables de las plantas, como semillas, y por otro, a la sobrestimación de aquellas partes fácilmente identificables como la epidermis de las hojas. En esta nota describimos una técnica simple para preparar los patrones de referencias de las varias capas que forman las semillas. Éstos son necesarios no sólo para identificar las especies de frutos de las plantas consumidas por los roedores sino también las partes de las semillas. Las ventajas del método propuesto son discutidas y comparadas con el método de Jeffrey.

Key Words: microhistological analysis, technique, seed, rodents

Determining animal diets is of great importance to ecological studies (Krebs 1989). The microhistological technique has been used extensively for diet analyses over the last 50 years (Dusi 1949, Neal et al. 1973, Hansen 1975, Merrill 1994, Campos 1997). Microtechnical procedures require the preparation of reference material from plants growing in the study area. To avoid serious errors in identifying diet components, reference materials must be prepared properly (Dusi 1949).

Rodents inhabiting arid regions are mainly omnivorous (Costa 1995). However, most of the information on the diets of desert rodents comes from species of the family Heteromyidae. These diets have been investigated fundamentally by inspection of the contents of cheek pouches (Reynolds 1958) although Reichman (1975) regards such contents as a poor indicator of what an animal eats. Diets of other groups of rodents have been analyzed using the microhistological technique (Meserve 1981, Ojeda et al. 1996, Campos 1997, Castellarini et al. 1998). Because rodent omnivory in arid environments is widespread (Costa 1995), new techniques are needed to increase the accuracy in identifying parts such as stems, seed, roots, etc. (Johansen 1940).

A maceration technique must be used to remove the epidermis of seeds, stems and bark. According to Johansen (1940), all stems can be disassociated into their components by using proper maceration methods. These can also be applied to seeds by treating them as though they were hard woody tissues. Jeffrey's method is one of the most frequently used for preparing reference slides of hard tissues such as seed (Dellafiore and Polop 1994, Castellarini et al. 1998). The purpose of this report is to describe the use of a sodium bicarbonate solution to macerate the seeds and dissolve the middle lamellae that bind the cells together for preparing reference slides for seed identification in rodent diets.

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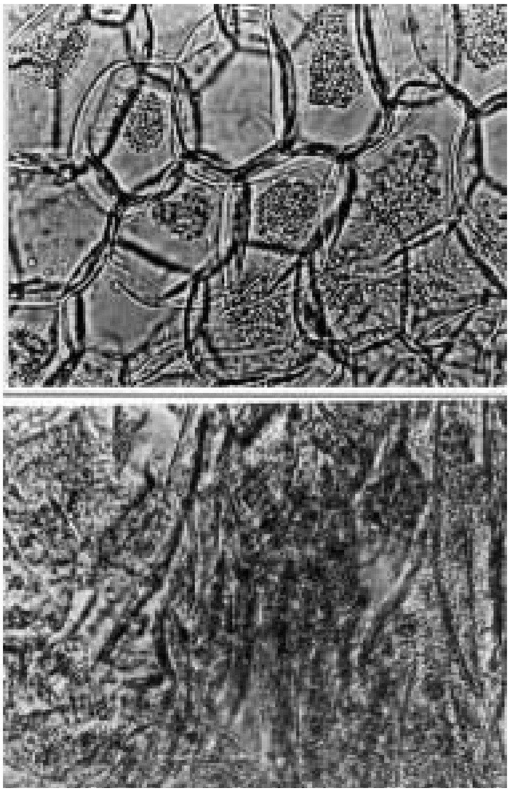
Materials and Methods

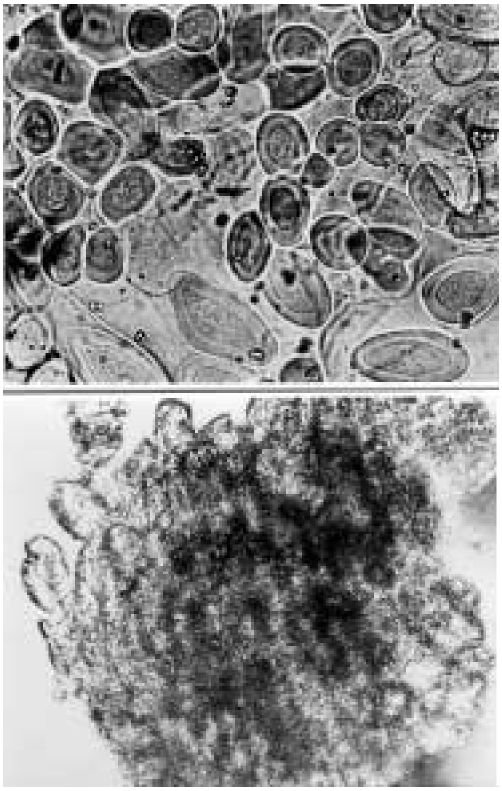
As proposed by Reichman (1975) for heteromyids, the term "seed" will be used to describe any seed or fruit of a plant eaten by rodents. Several hard, tightly bound layers of tegument usually form the external coat of seeds and are very difficult to separate, hindering preparation of reference slides and impeding seed identification in the diets of rodents. The solution to this problem lies in using effective fluids to saturate the seeds' external layers so that they can be separated. We addressed this problem using a macerating solution of 17.5% $NaHCO_3$ (sodium bicarbonate). The seeds were soaked from 24 to 36 hours, depending on the seed coat thickness. This soaking process softened the hard parts of the seeds and facilitated separation of the different parts under a binocular magnifying glass with the help of tweezers and a scalpel.

Every seed part, including the endosperm and embryo, was scraped, then cleared by soaking in a solution of 50% sodium hypochlorite (household bleach) for 20 min and then washed with abundant distilled water. These parts were mounted separately onto slides in a drop of pure glycerin. Cover slips were added



a

b



a

b

Fig. 1. Photomicrographs of reference slides at 400x magnification of the eternal layers of seeds from *Larrea divaricata* prepared with the sodium bicarbonate method (a) and the Jeffrey's method (b).

Fig. 2. Photomicrographs of reference slides at 400x magnification of starch from *Prosopis Flexuosa* seeds prepared with the sodium bicarbonate method (a) and the Jeffrey's method (b).

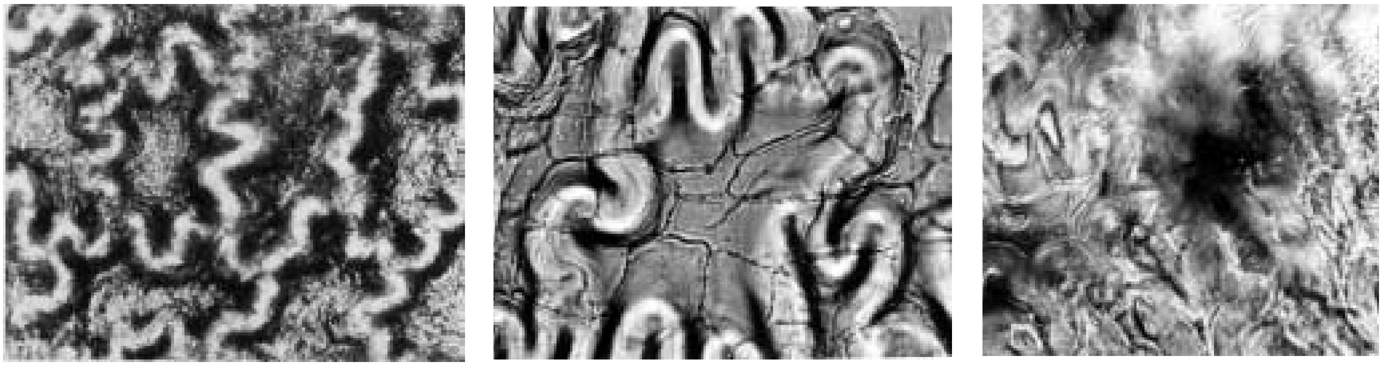
cautiously and a coating of transparent nail polish was brushed over their margins to seal the mounts.

Reference slides were prepared using both Jeffrey's method and the technique proposed in the present note, in order to compare sharpness obtained. Jeffrey's method (Johansen 1940) is a dissociation technique, and its procedure is as follows: first the material (either fresh or dry) is cut into small slices or slivers about 300 micras thick, boiled and cooled repeatedly until free from air (a suction pump may be used for the same purpose). Then it is macerated in a solution of equal parts of 10% aqueous nitric acid and 10% aqueous chromic acid. The time varies according to the material, but cells should begin separating in about 24 hours. A thick glass rod with rounded end may be used to crush the material very gently. If it does not crumble easily, the macerating mixture can be replaced with fresh fluid, and then must be washed thoroughly with water to remove the acids. Finally the material is stained with any suitable basic stain; safranin may be recommended.

We used seeds of 4 shrub species from the Monte desert (Argentina): *Bulnesia retama* (Gill. Ex Hook.) Griseb., *Larrea divaricata* Cav., *Lycium chilense* Miers, and *Prosopis flexuosa* D.C. *Bulnesia retama* (Zygophyllacea) has dry dehiscent fruits (capsules), *L. divaricata* (Zygophyllacea) has schizocarp fruits divided at maturity into 5 hirsute and uniseminate mericarps, *L. chilense* (Solanaceae) has a pluriseminate suborbicular berry (Peralta and Rossi 1997), and *P. flexuosa* (Leguminosae) fruit is a modified indehiscent legume with a thin epicarp, a mesocarp which can be either fleshy, sugary or fibrous, and several uniseminate endocarp segments (Burkart 1952). A sample of the feces of *Eligmodontia typus* Cuvier (Muridae, Rodentia) collected in the field was prepared following the procedure proposed by Williams (1969) to compare the seed coat layers of *L. chilense* with the reference slides. We selected this shrub because it is frequently found in this rodent's diet (Giannoni and Dacar unpublished data). Photomicrographs of the reference slides and of feces were taken with an optic microscope at 400x magnification, except for those epidermal tissues having very long hairs (trichomes) which were photographed at 200x magnification.

Results and Discussion

Remarkable differences were found in comparing reference slides prepared using the sodium bicarbonate solution method compared with Jeffrey's method. The former technique helps soften the seed coat layers, thus allowing their separation and removal with tweezers, making preparation of reference slides easier. With Jeffrey's method, all seed coat layers are mixed together and preparation of slides is consequently more difficult, as observed in comparing the external layers of *Larrea divaricata* obtained with both methods (Fig. 1a and 1b). The sodium bicarbonate solution makes it possible to create reference slides of starches from *Prospis fleuosa* seeds, as shown in Fig. 2a, which we could not achieve with Jeffrey's technique (Fig. 2b). In comparing the photo of *Lycium chilense* seeds obtained from feces (Fig. 3a) with reference slides of this plant species prepared with both methods (Fig. 3b and 3c), the sodium bicarbonate maceration technique provided much more recognizable parts of fruits consumed. A comparison of *Bulnesia retama* seeds, which had trichomes, again showed that

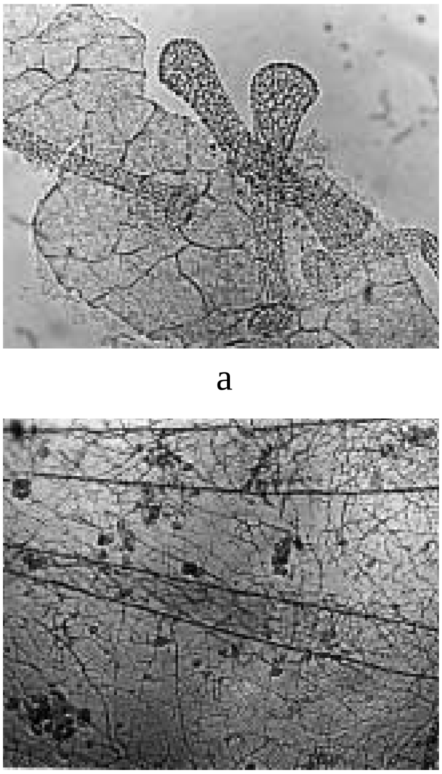


a b c

Fig. 3. Photomicrographs of slide at 400x magnification of *Lycium chilense* seeds prepared from feces of *Eligmodontia typus* (a) compared to reference slides prepared with the sodium bicarbonate method (b) and the Jeffrey's method (c).

reference slides prepared with the sodium bicarbonate method (Fig. 4a) were more distinct than slides prepared with the Jeffrey's method (Fig. 4b).

The proposed technique has several advantages. It is a simple process for preparing reference slides of seed that does not require expensive or dangerous chemical compounds. Because the sodium bicarbonate solution does not deteriorate plant tissues, the material may remain at least 4 months in the maceration solution before the reference slides are prepared (Dacar personal observation). In addition, this technique permits separation of seed coat layers, making it possible to identify not only the plant species but also the seed parts consumed, including starches. The sodium bicarbonate solution can be used in fresh and fossil feces and provides improved identification of epidermal tissues under the microscope (Dacar personal observation). Reference slides can be prepared from herbarium material, which is hydrated after being soaked in the sodium bicarbonate solution (Unpublished data, Dacar). In conclusion, the technique proposed allows for an easier and better preparation of reference slides of hard tissues, such as seed, which usually need elaborate maceration techniques.



a

b

Fig. 4. Photomicrographs of reference slides at 200x magnification of *Bulnesia retama* seeds with trichomes prepared with the sodium bicarbonate method (a) and the Jeffrey's method (b).

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Technical Note: Physical and chemical comparisons between microphytic and non-microphytic soil seedbeds

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Abstract

In arid and semi-arid climates, the physical and chemical nature of the soil seedbed greatly effects success or failure of plant recruitment. We hypothesized that the presence or absence of microphytic soil crusts may influence the character of soil seedbeds. To test this hypothesis, we compared chemical and physical attributes of the soil seedbed (0-6 cm) between adjacent areas of well-expressed microphytic soil crusts and non-microphytic soil surfaces for 2 sites on granitic alluvial fans in northwestern Nevada. As compared with non-microphytic areas, microphytic soil seedbeds were finer-textured and contained more DTPA-extractable Mn, Cu, and Zn. Further research should examine in greater detail the role of microphytic soil surfaces in eolian dust entrapment, its relationship to nutrient deposition, and the interaction with seed recruitment.

Resumen

En climas áridos y semiáridos, la naturaleza física y química del suelo de la cama de siembra afecta grandemente el éxito o fracaso del establecimiento de plántulas. Nosotros hipotetizamos que la presencia o ausencia de costras de suelo microfiticas puede influenciar la características del suelo de la cama de siembra. Para probar esta hipótesis comparamos los atributos físicos y químicos del suelo de la cama de siembra (0-6 cm) entre áreas adyacentes con costras de suelo microfiticas bien definidas y áreas sin costras microfiticas, la comparación se realizó en 2 sitios de abanicos aluviales graníticos del noroeste de Nevada. Comparado con el de las áreas sin costras microfiticas, el suelo de las áreas con costras microfiticas fue de textura mas fina y contenía mas Mn, Cu, y Zn extractables con DTPA. Investigaciones futuras deben examinar a mayor detalle el papel de la superficie del suelo microfitico en atrapar el polvo eólico, su relación con la deposición de nutrientes y la interacción con el reclutamiento de semillas.

Key Words: ammonium, eolian dust, micronutrients, nitrate, particle size distribution

The soil surface of arid and semi-arid regions is often covered by a complex assemblage of algae, cyanobacteria, fungi, lichens, and mosses. These microphytic or cryptobiotic crusts exhibit a host of functions including soil stabilization, nitrogen fixation, and enhancement of water regimes (Klubek and Skujins 1980, Anderson et al. 1982, West 1990, Verrecchia et al. 1995). In arid and semi-arid climates, eolian dust deposition is an important component in soil genesis and nutrient transport (Chadwick and Davis 1990, Reheis 1990, Offer et al. 1992, Blank et al. 1999). Our purpose was to determine if the rough pinnacled surfaces characteristic of microphytic crusts foster the entrapment of eolian dust and consequently influence the particle size distribution and nutritional status of the soil seedbed.

Materials and Methods

The study area is about 30 km north of Reno, Nev. (119° 50' E, 39° 51'N). Two sites were chosen for detailed study based on the availability of livestock exclosures which facilitated differential expression of microphytic surface soil communities (Johansen and St. Clair 1986). The Bedell Flat site is near the western edge of the valley on the lower portion of an alluvial fan in the northwest corner of section 22, T 23N R 19E. The slope is less than 4 percent, the aspect is northeast, and elevation is 1548 m. The soil is mapped as the Bedell series, a coarse-loamy, mixed, mesic, Aridic Argixeroll developed in mixed colluvium dominantly from granite. Following a wildfire in 1953, the site was seeded with crested wheatgrass (*Agropyron desertorum* [Fisher] Schultes). An exclosure was built in 1958. Present vegetation consists of crested wheatgrass, cheatgrass (*Bromus tectorum* L.), big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.), needle-and-thread (*Hesperostipa comata* Trin. & Rupr.), Thurber's needlegrass (*Achnatherum thurberianum* [Piper] Barkworth), squirreltail (*Elymus elymoides* [Raf.] Swezey) and green rabbitbrush (*Chrysothamnus viscidiflorus* [Hook.] Nutt.). By visual estimates, the enclosed area contains more crested wheatgrass and less green rabbitbrush than the grazed area. The microphytic crust in the exclosure is dominated by tortula moss with pronounced microrelief.

The Dogskin Mountain site is on the upper portion of an alluvial fan in the southeast corner of section 12, T 23N R 19E. Slopes are 8 to 15%, aspect is southwest, and elevation is 1695 m. The soil is mapped as the Haybourne series, a coarse-loamy, mixed, mesic Xeric Haplocambid (Baumer et al. 1983). The surface texture is gravelly loamy sand to sandy loam. The exclosure was built approximately 20 years ago. Vegetation is similar within and outside the enclosure and consists of big sagebrush, green ephedra (*Ephedra viridis* Cov.), desert peach (*Prunus andersonii*

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A. Grey), Indian ricegrass (*Achnatherum hymenoides* Roemer & Schultes), and desert needlegrass (*Achnatherum speciosum* Trin. & Rupr.). Given the large stature of sagebrush, wildfire has not burned the site for at least the last 30 years. The microphytic crust, which is not as well-expressed nor covers as much surface as on the Bedell site, is dominated by crustose and foliose lichens creating a locally pinnacled to undulating soil surface.

Soil samples (4 replicates) were randomly collected from shrub interspace positions lacking vascular plant cover in microphytic (inside exclosures) and non-microphytic (adjacent non-exclosed areas) microsites on June 1993. We used a round cylindrical steel sampling device with diameter of 12 cm and depth of 6 cm. For particle size measurements, a portion of air-dried soil was passed through a series of sieve sizes and the weight retained in each sieve was recorded. The rest of the soil tests were performed on air-dried material passed through a 2-mm sieve. Organic carbon was quantified by the Walkley-Black method with a digestion temperature of 150°C with no correction factor (Nelson and Sommers 1982). The Kjeldahl method was used to quantify organic nitrogen (Bremner and Mulvaney 1982). Micronutrient bioavailability was gaged by DTPA-extraction (Lindsay and Norvell 1978). Plot (microphytic and non-microphytic) differences for measured soil attributes were determined separately for each location using an unpaired T-test with significance judged at the $p \leq 0.05$ level.

Results and Discussion

Microphytic soil seedbeds are significantly finer-textured than non-microphytic seedbeds (Table 1). Undulating topography of microphytic soil surfaces traps eolian dust fostering finer soil surface textures which influences soil moisture relations and soil nutrition (Kleiner and Harper 1977, Verrecchia et al. 1995, Anderson et al. 1982, Danin and Gaynor 1991). Content of organic C, Kjeldahl N, and C to N ratios did not statistically differ between microphytic and non-microphytic treatments (Table 2). Microphytic crusts have been shown to contribute photosynthetic C directly to the soil (Beymer and Klopatek 1992). DTPA-extractable Cu, Zn, and Mn were higher, in some cases statistically higher, in microphytic soil seedbeds compared to non-microphytic soil seedbeds (Table 2). Given that rate of chemical extraction is proportional to surface area, higher content of micronutrients may be explained by finer textures in microphytic soil seedbeds. Greater availability of Cu, Zn, and Mn would be favorable to higher plant growth. These metals, however, were not significantly higher in tissue of *Festuca* and *Mentzelia* associated with cryptobiotic crusts (plant content of Fe was higher) (Belnap and Harper 1995).

Table 1. Weight percent of various particle size fractions for microphytic and non-microphytic seedbeds for the studied sites.

Particle fraction (mm)	Location: Bedell Flat Micro	Bedell Flat Non	Dogskins Micro	Dogskins Non
	(%)			
> 3.35	1.5	1.2	3.7	3.6
2.80–3.35	0.8	0.9	2.1	2.9
2.00-2.80	3.3 a	4.6 b	7.9 a	12.4 b
1.00-2.00	9.8 a	15.4 b	19.1 a	33.5 b
0.50-1.00	10.3 a	17.4 b	19.5 a	24.5 b
0.25-0.50	13.2	15.0	12.1	9.8
0.18-0.25	8.9 a	7.5 b	6.5 a	3.3 b
< 0.180	52.1 a	38.1 b	29.1 a	9.9 b

For each location, significant differences between microphytic and non-microphytic plots are denoted by different letters.

Table 2. Selected soil attributes for microphytic and non-microphytic seedbeds for the studied sites.

	Location: Bedell Flat Micro	Bedell Flat Non	Dogskins Micro	Dogskins Non
Organic C (%)	1.19	1.31	0.61	0.53
Kjeldahl N(%)	0.17	0.15	0.04	0.04
C:N ratio	8.4	10.5	14.2	16.9
DTPA Fe (mg kg^{-1})	2.1	2.0	1.1	1.0
DTPA Mn (mg kg^{-1})	5.7	5.3	2.4 a	1.7 b
DTPA Cu (mg kg^{-1})	12.5 a	11.0 b	12.3 a	8.7 b
DTPA Zn (mg kg^{-1})	8.1	6.8	6.0 a	3.5 b

For each location, significant difference between microphytic and non-microphytic plots are denoted by different letters.

Implications

A voluminous literature documents the importance of soil surface microflora in a plethora of ecological processes (West 1990, Johansen 1993, Eldridge and Greene 1994). Our research further documents that well-expressed microphytic surfaces occupied by lichens and mosses, through the capture of eolian dust, create a significantly finer-textured soil seedbed compared to adjacent seedbeds not occupied by lichens and mosses. Given the relatively short time-frame (Bedell Flat exclosures < 40 years; Dogskins exclosures < 20 years) to produce these differences in seedbed particle size distribution, microphytic crusts likely play an important role in cycling of eolian dust on rangelands (Williams et al. 1995, Leys and Eldridge 1998) and concomitantly on nutrient levels and the physical nature of soil seedbeds.

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Technical Note: Early harvest of squirreltail seed

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Abstract

Squirreltail (*Sitanion hystrix* (Nutt.J. G. Smith), a native, cool-season perennial bunchgrass of the Intermountain West has been shown to reinvade degraded rangelands invaded by exotic annual weeds. However, one limitation to mechanical seed collection of this species is the disarticulating nature of the rachis at seed maturity. The purpose of this reseach was to determine if early harvest of the inflorescence before disarticulation would result in viable seed. After anthesis, seeds were collected weekly in 1995 and about every 10 days in 1996 at a research site near Prineville, Oregon. Seeds were germinated for 21 days at a constant temperature of 20°C. Germinable seeds were present at all collection dates from late anthesis to seed shatter in 1995, and all but early anthesis in 1996. Total germination, rate of germination and seed weight increased as seeds were collected later in the summer. Collection of squirreltail seed when a majority of seed awns have moved from a reddish to a divergent, straw colored appearance resulted in germination properties similar to fully mature seed. This occured about 1 week prior to the onset of seed head disarticulation.

Key Words: Germination, phenology, competition, restoration

Resumen

El zacate "Squirreltail" (*Sitanion hystrix* Null. J.G. Smith) es una especie nativa perenne de estación fría de la región intermontana del oeste que ha sido demostrado que reinvade los pastizales degradados e invadidos con malezas anuales exóticas. Sin embargo, una limitante para la cosecha mecánica de semilla de esta especie es la naturaleza desarticulante del raquis cuando la semilla esta madura. El proposito de este estudio fue determinar si la cosecha temprana de la inflorecencia, antes de la desarticulación, producirá semilla viable. En un sitio experimental cerca de Prineville, Orergon se colecto semilla después de la antesis, la colecta se hizo semanalmente en 1995 y cada 10 días en 1996. Las semillas se germinaron durante 21 días a temperatura constante de 20°C. En 1995 hubo semillas germinables en todas las fechas de colección, desde fines de la antesis hasta la caída de la semilla, en 1996 en todas las fechas, menos en el inicio de la antesis, también hubo semilla germinable. La germinación total, la tasa de germinación y el peso de la semilla aumento conforme las semillas se colectaron al final del verano. La colecta de semilla de "Squirreltail" cuando la mayoría de las aristas de la semillas han cambiado de rojizo a divergente y la apariencia de la paja es coloreada resulto en propiedades de germinación similares a los de semilla totalmente madura. Esto ocurrió aproximadamente 1 semana antes del inicio de la desarticulación de la inflorecencia.

Squirreltail (*Sitanion hystrix* (Nutt.J. G. Smith)=*Eylmus elymoides* (Raf.)Swezey)] is a short-lived, cool season perennial grass native to a diverse number of arid habitats in the Intermountain West. Generally considered a low-seral species, it is often observed to be one of the few native grasses capable of reestablishing on rangelands that have been invaded and dominated by alien annual species such as medusahead (*Taeniatherum caput-medusae* ssp. *asperum* (Sink.) Melderis) and cheatgrass (*Bromus tectorum* L.) (Hironaka and Tisdale 1963, Hironaka and Sindelar 1973, 1975). Rapid seed germination, vigorous seedling development, and the presence of a disarticulating seed head that facilitates seed dispersal by wind are characteristics promoting the establishment of this species on weed dominated sites (Hironaka and Sindelar 1973, Mack and Pyke 1984, Jones 1998).

Although squirreltail would seem an excellent species for revegetation purposes, the disarticulating nature of the rachis poses a limitation to mechanical seed collection (Young and Evans 1977). The objective of this research was to determine if harvest of the inflorescence before disarticulation would result in viable seed.

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Materials and Methods

Seed collection and processing

Squirreltail seeds were collected during the summers of 1995 and 1996 on a site near Prineville, Ore. (T 15S R17E Sec.18). The collection site was at an elevation of 1,140 m and characterized by a dominance of < 100 year old western juniper (*Juniperus occidentalis* Hook.), big sagebrush (*Artemisia tridentata* Nutt.), low sagebrush (*Artemisia arbuscula* Nutt.), bluebunch wheatgrass (*Agropyron spicatum* Pursh syn. *Pseudoroegneria spicata* (Pursh) A.Love), Idaho fescue (*Festuca idahoensis* Elmer), and squirreltail. The 2,000 m^2 site was cleared of western juniper during the fall of 1982 and allowed to revegetate naturally (Vaitkus and Eddleman 1991). Squirreltail cover on the site in 1995 was approximately 1.2 % (L. E. Eddleman unpublished data). Soils on the study site have been classified as relativley shallow (330 mm), clayey-skelatal, frigid Pachic Argixerolls (Vaitkus and Eddleman 1991).

Seeds were collected from squirreltail individuals throughout the plot beginning approximately 2 weeks following anthesis and ending when a majority of seed heads were disarticulating. In 1995, seeds were collected at 1-week intervals from 21 June to 26 July. In 1996, seeds were collected at approximately 10-day intervals from 21 June to 23 July. Phenology of squirreltail plants was recorded at times of collection.

Inflorescences were placed in paper bags and stored at room temperature. Seeds were cleaned using a small mechanical thresher, which also removed the awn. Light, unfilled seeds were seperated maually by placing on a light table.

Experimental procedure

Seeds were germinated in an environmental chamber at 20° C (+/-3° C) in darkness (Young and Evans 1977). Four replications of 25 seeds each were used for each collection. Seeds were imbibed with distilled water on cellulose pads in plastic petri dishes. Germination counts were made for 21 days. A seed was considered germinated when either radicle or plumule had grown at least 2 mm. Seeds collected in 1995 were germinated during May 1996 and seeds collected in 1996 were germinated in November 1996. The germination count was made daily from the third day of the trial for the May 1996 test, and from the first day of the Nov. 1996 test. In addition to germination counts, 5 replicates of 25 air-dried seeds were weighed for seed collected in both years.

Total germination percentage, days to 50% germination, and seed weight were used to assess differences between collection dates. An analysis of variance was used to assess germination response. When a significant F test (P = 0.05) was found in the analysis of variance, a protected Least Significant Difference mean comparison test was applied to assess differences among collections within a year (Steel and Torrie 1980). Only significant differences (P = 0.05) are reported in the text.

Results and Discussion

Squirreltail required 4 to 5 weeks to reach disarticulation after anthesis (Table 1). When awns were a reddish color and seeds progressing into a hard dough stage, about 14 days remained until active disarticulation.

Early seed harvest before the hard dough stage provided germinable seeds while at the same time avoided disarticulation of the seed head. Germinable seeds were present in all collections of 1995 seeds, and in all collections of 1996 seeds except for 21 June (early anthesis stage) (Table 2). In both years total germination percentages increased with seed maturation, with greater than 80% germination after the mid-to late-dough stages. Germination percentages were not different among the 12 July, 19 July, and 26 July dates in 1995. In 1996, no differences were found between the 11 July and 23 July collections.

Speed of germination was similar among the collections in 1995 except for slower germinating seeds on 28 June (Table 2). For 1996, fastest germination was for the later harvested seeds. In the event that a seed lot exhibits slow germination rates, a seedling may be put at risk on weed infested sites. Depletion of soil moisture by competing species usually conveys a late-emerging seedling to dessication and death (Harris 1967, Pyke 1990). In squirreltail, later harvest resulted in greater total germination and for 1996, more rapid germination. Trying to maximize these attributes in a seed lot is important because they may impart a greater chance of seeding success in competitive environments.

Reasons for lower germination amounts in earlier collected squirreltail seeds may be related to seed weight and maturation of

Table 1. Phenological description of Squirreltail at the time of collection.

Date	Description
	-1995-
21 June	Majority of flowering culms in mid to late anthesis, approximately 15% just out of the boot stage.
28 June	Approximately 10% of inflorescences approaching maturity, majority of inflorescences in late flowering or florets in early soft dough state of seed development.
5 July	Majority of florets in early to mid-dough stage of development.
12 July	Majority of florets in late dough state, awns are turning red, < 5% of inflorecences are mature. Plants beginning to turn a straw/red color.
19 July	Approximately 50% of all inflorescences are mature as evidenced by straw color and divergent awns. The other inflorescences still with red awns and embryo is in hard dough stage.
26 July	> 75% of inflorescences are mature and disarticulating. < 25% of inflorescences are late maturing and awns still red and straight.
	-1996-
21 June	Inflorescenses in late boot stage to early anthesis.
1 July	Majority of inflorescenses exhibit red awns, seeds in mid-dough stage.
11 July	Majority of inflorescences with straight, red awns, seeds hard.
23 July	> 90% of inflorescences mature and beginning to disarticulate. Awns divergent, approximately 10% of inflorescences with straight red awns.

Table 2. Mean percent germination and days required for 50% germination, and seed weight (gram per 100 seeds) of Squirreltail seeds collected in 1995 and 1996.

Collection date	Germination percentage	Days to 50% germination	Seed weight
1995	(%)	(Days)	(g/100 seeds)
21 June	20c[1]	5.5ab	0.12c
28 June	8d	6.8a	0.16c
5 July	80b	5.5ab	0.24b
12 July	99a	5.0b	0.24b
19 July	94a	4.0b	0.36a
26 July	100a	4.0b	0.40a
S.E.D.[2]	1.72	0.6	0.04
1996			
21 June	0a	--	0.09c
1 July	41b	4.3a	0.12d
11 July	81c	2.8b	0.18b
23 July	99c	2.0a	0.32a
S.E.D.	2.2	0.3	0.04

[1]Means followed by a similar letter are not significantly different within a year (P ≤ 0.05).
[2] Standard error of the difference.

the seed head at the time of collection. In both 1995 and 1996, weight of seeds became significantly heavier for seeds collected later in the growing season (Table 2). Heavier seeds within a seed lot have been shown to exhibit higher germination amounts and better seedling emergence characteristics than lighter seeds (Aiken and Springer 1995, Limbach and Call 1996, Hou and Romo 1998). Seeds collected later in the process of seed head maturation also exhibit greater seed germination amounts (Phaneendranath et al. 1978). Attention to maximizing seed weight and harvesting seed heads close to maturity are important considerations when trying to optimize revegetation success.

Management Considerations

Squirreltail appears to hold desirable properites to aid in restortion of degraded sagebrush grasslands in the Intermountain West. When seeds of squirreltail are collected, it is recommended they be made as close to inflorescence disarticulation as possible. When approximately 50% of seed heads have divergent awns and the other half have straight awns but a reddish color, seeds will exhibit strong germination properties. This generally corresponds to a week before seed head disarticulation and may make harvesting with mechanical devices easier. Control of competing vegetation, although beneficial for all seedings, would be critical for earlier harvested seed.

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Book Review

Dynamic State Variable Models in Ecology: Methods and Applications. By Colin W. Clark and Marc Mangel. 2000. Oxford University Press, New York and Oxford. 289 p. US$65.00 hardback. ISBN 0-19-512266-66.

In their 1988 book *Dynamic Modeling in Behavioral Ecology*, Colin Clark and Marc Mangel showed how the techniques of dynamic programming can be used to construct and analyze a wide range of models in ecology. This book continues that line of inquiry. Specifically, the authors use the 12 chapters of this book to show how the methods of dynamic programming can be used to comprehend topics as diverse as the oviposition behavior of insect parasitoids, the reproductive strategies of bushmen females, and flowering in thistles and other monocarpic perennials. In the rest of this review, I shall first comment on 5 of the book's 12 chapters. I shall then conclude with some general observations. This should provide the reader with a good idea of the intellectual contributions of this book.

Chapter 1 acquaints the reader with a particular "way of conceptualizing constraints and trade-offs in biology" (p. 3). After introducing the reader to the so called "fitness function," the authors rightly spend a considerable amount of time telling the reader that the key to computing the fitness function in any given situation lies in writing down the associated dynamic programming equation correctly. The use of the computer is stressed repeatedly and, somewhat quixotically, the authors use the term "dynamic state variable model" to refer to a dynamic programming model. We are told that even though dynamic state variable models cannot easily incorporate certain ecological factors such as population and community level effects, these models are very useful because, *inter alia*, they "are more flexible than rate-maximizing and similar models" (p. 39).

Can "observed behavior be predicted from the adaptationist hypothesis, in quantitative terms, based on known, measurcd parameter values, and including important trade-offs?" (p. 71). This question is the focus of Chapter 3. The authors claim that if one proceeds systematically through the various stages of the construction and the analysis of a dynamic state variable model, then such a model can shed valuable light on the above question. Although this contention is probably correct, the predictions of dynamic state variable models can be criticized on grounds of complexity. In other words, one could credibly claim that the predicted behavioral strategies emanating from dynamic state variable models are simply too complex to ever evolve by natural selection. Although the authors are aware of this point, this chapter would have profited from a more elaborate discussion of this point.

Chapter 6 shows how dynamic state variable models can be used to make interesting predictions about avian migration in general and the spring migration of western sandpipers in particular. How might we combine knowledge of the ecology of the western sandpiper with a fitness maximization hypothesis to explain the observed migration pattern of this bird? The authors construct a dynamic state variable model and show "that the ability to utilize favorable winds nearly optimally may be an important component of fitness..." (p. 159). Although the analytics of this demonstration are both complete and worthwhile, the same cannot be said about the partially developed single flight migration model of Section 6.3. Oddly, the authors neither code nor attempt to obtain predictions from this thought provoking, 2 state-variable model.

This book's most fascinating application of a dynamic state variable model is discussed in Chapter 7. Here, the authors note that Bushmen females "space their children quite far apart and typical interbirth intervals (IBIs) range from three to five years" (pp. 167–168). Is this optimal behavior? In particular, is it the case that the work load of women who use shorter IBIs is just too great to bear? To answer this question, the authors analyze a dynamic state variable model and nicely show that this model of "reproductive behavior [is] successful in predicting dynamic interbirth intervals that agree with field data" (p. 172).

Chapter 11 contains a stimulating discussion of uncertainty and information as a state variable. Pointing to the difference between stochasticity and uncertainty, the authors correctly point out that "the parameters that characterize the probability of finding food or avoiding predation may themselves have probability distributions that characterize imperfect *knowledge*, rather than uncertain *events*" (p. 232, emphases in original). This observation forms the basis for the study of a Bayesian foraging model in which the copiousness of food in a certain habitat varies from one year to the next. The authors analyze a perfect-information scenario, a no information updating scenario, and a Bayesian information updating scenario and show that "the Bayesian forager obtains fitness intermediate between the cases of zero information and perfect information" (p. 244).

Let me now comment briefly on some of the not so laudable aspects of this book. First, a terminological issue. The authors claim that the expression "dynamic state variable model" is an improvement over "dynamic programming model." I beg to differ. Not only is the former expression unwieldy but it also suggests that the constraints in this modeling framework are all state variables. It's not obvious that this is always the case. Further, if the authors truly believed that "dynamic state variable model" is a superior expression, then they should have used this expression consistently in the book. On more than one occasion (see p. 254 and p. 263), the authors revert to dynamic programming, thereby undermining their own claim that relative to "dynamic programming model," "dynamic state variable model" is a superior expression. Second, while the authors are certainly cognizant of extant criticisms of dynamic programming models, they pay insufficient attention to this issue. Given the extent to which the authors push dynamic programming models in this book, it would have been nice to learn more about their views on the relevance of these criticisms in specific ecological contexts. Finally, the authors pay no attention whatsoever to solving the dynamic programming equation analytically. It is certainly not true that dynamic programming equations can never be solved analytically but it may be the case that ecologically meaningful dynamic programming equations can only be solved with a computer. If this is the case, then some commentary on this issue would have been helpful. More generally, with regard to this issue, I would have preferred a marriage of the approach in Marc Mangel's splendid *Decision and Control in Uncertain Resource Systems* with the approach of this book.

These jeremiads notwithstanding, let me conclude this review by noting that in this book, 2 prominent researchers have provided a competent analysis of dynamic programming models in ecology. Consequently, I recommend this book to quantitatively inclined ecologists and to all others who are interested in learning more about how dynamic programming techniques can be used to construct and analyze mathematical models.—*Amitrajeet A. Batabyal*, Rochester Institute of Technology, Rochester, New York.

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Remote Sensing/GIS Symposium

Paper Synopsis

Full version of these papers can be found at http://uvalde.tamu.edu/jrm/remote/index.htm
or by accessing the Society for Range Management web site at http://www.srm.org/

The Remote Sensing and Geographic Information Systems Committee of the Society for Range Management encourages understanding and application of remote sensing and GIS technologies. These technologies have undergone explosive growth over the last decade. Satellites now provide panchromatic images with 1meter ground resolution and new satellite vehicles have been approved that will provide one half meter images. Three-dimensional mapping of the Earth's surface is yielding topographic models with precision and resolution that were impossible just a few years ago. Information collected by researchers working on rangelands can be spatially positioned, incorporated into electronic databases, and distributed worldwide nearly instantaneously via the Internet.

We have been propelled into this "information age" by the development of computers and digital storage media, facilitated by digital imagery and electronic measurement devices. The pace has been dizzying but the rewards are great. Managers can draw on these analytical tools to predict fire hazard, range readiness, or developing famines. We can watch the weather as it unfolds half a world away or, through the miracle of technology, view road conditions at the local mountain pass via a web camera. Scientists are using the technology to track weed infestations, insect outbreaks, or plant pathogens as they move across the landscape. Using historical aerial images we can view the development of brush in a pasture or the subtle movement of a stream through the decades.

The Remote Sensing/GIS Committee believes that this is just the beginning. Many applications are currently being developed. In this Electronic Section of the *Journal of Range Management* we are attempting to utilize recent advances in computer, internet, and compact disk technologies to facilitate the flow of information from remote sensing and GIS specialists to range professionals. It is our hope that subscribers and readers of the *Journal* will gain understanding and insight into these new and powerful tools for natural resource management. The articles contained in this section represent only a fraction of the broad and varied applications that have potential for rangelands. Specialists are augmenting traditional uses of remote sensing and GIS for rangeland inventory, monitoring, and management with new and exciting tools such as airborne laser technology, modeling of plant phenological development, and time change analysis. If we have shared, through this electronic section, some of our insight, enthusiasm, and excitement then our efforts have been worthwhile.

We would like to thank the Society for Range Management for sponsoring the Remote Sensing/GIS Symposium at their 53rd Annual Meeting in Boise, Idaho. Thanks go to Dr. Patrick Clark and Dr. Mark Seyfried for organizing the symposium. Pat Shaver's guidance and encouragement brought this project to successful completion. Special thanks are due to Gary Frasier for invaluable editorial assistance and support Marc Laliberte, Keith Owens, and James Utterback for HTML and Internet programming.

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A method to incorporate phenology into land cover change analysis

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http://uvalde.tamu.edu/jrm/remote/pheno-paper.htm

Abstract

Land cover change analysis is an important and common image processing technique. Normally, change analysis is performed between 2 images that have been matched by calendar date instead of using some form of environmental criterion. Under this scenario, detected changes may only reveal differences in phenology and not real differences in vegetative land cover trends.

Two primary factors influence the phenology of the environmental year. These are growing degree-days (GDD) and accumulated precipitation (AP). Other factors are important as well (e.g., humidity, wind, the rate and form of accumulated precipitation, and the precipitation regime from recent years), but growing degree-days and accumulated precipitation appear to be the best correlates with phenology. The potential errors and biases associated with this model are discussed.

The author developed a software program (Pheno-Calc) that allows the user to calculate GDD and AP, graph and view the data set, and perform match calculations. Match calculations allow the user to more strategically choose remotely sensed imagery for analysis of land cover change by providing the dates on which GDD and/or precipitation accumulation has been matched.

Resumen

El análisis del cambio de cobertura es una técnica importante y común en el procesamiento de imágenes. Normalmente, el análisis de cambio se hace entre dos imágenes que se han enparejado por fecha del calendario en vez de algún forma de criterio medioambiental. Bajo este escenario, los cambios detectados quizás puedan enseñar solamente las diferencias de fenología y no de diferencias verdaderas en la tendencias de cobertura vegetal.

Hay dos factores primarios que influyen en la fenología del año medioambiental. Estas son el índice de unidades de calor acumuladas (grados-días de crecimiento) y la precipitación acumulada. También, hay otros factores importantes (p.ej., la humedad, la velocidad de viento, la tasa y el patrón de precipitación acumulada, y el régimen de precipitación de los años recientes), pero parece que el índice de grados-días de crecimiento y la precipitación acumulada proveen la mejor correlación con la fenología. La potentia de errores y las inclinacimes associa dos con este modelo, se discuten.

El autor ha desarrollado un programa de ordenador (Pheno-Calc) que permite al usuario de calcular los grados-días de crecimiento y la acumulación de precipitación, visualizar y gráficar datos, ejecutar cálculos de coincidencias. Los grados-días de crecimiento y/o la acumulación de precipitación, el cálculo de coincidencias permite que al usuario elegir mejor los imágenes de teledetección para el análisis de cambio de cobertura por medio deproveer las fechas en que coinciden.

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Airborne LASER technology for measuring rangeland conditions

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Key Words: scanning laser, fractal, vegetation, landscape
http://uvalde.tamu.edu/jrm/remote/srm-laser.htm

Abstract

Land surface and vegetation properties are key for understanding range conditions. Ground-based measurements of these properties are difficult and time-consuming. Profiling and scanning airborne laser altimeter systems provide an alternative method to quickly and easily measure land surface and vegetation features and properties for large land areas. The agreement between airborne laser altimeter and field measurements is good for topographic features, vegetation properties (i.e., height, cover), and surface roughness. This paper presents examples of the applications of profiling and scanning airborne lasers as additional tools in the arsenal of remote sensing tools used to monitor rangeland conditions. Airborne laser measurements of plant canopy properties across the landscape and their effects on aerodynamic roughness allow better understanding of evaporative losses, infiltration, and surface water movement. Laser measurements improve our understanding of the effect of canopy and landscape roughness on rangeland conditions.

Resumen

Las propiedades de la superficie del terreno y de la vegetación, son claves para entender las condiciones de los pastizales. Las medidas de estas propiedades son difícil y se requiere mucho tiempo. Los sistemas de altímetro láser de perfileado y escaneo proveén un método alternativo para medir rápidamente y fácilmente la superficie del terreno y las características de la vegetación, las medidas del propiedades de grandes áreas de terreno. La concordancia entre el altímetrro láser aéreo y las medidas del campo son apropiadas para las características topográficas, las propiedades de la vegetación (por ejemplo, altura y covertura) y la tosquedad de la superficie. Este manuscrito presenta ejemplos de aplicaciónes del perfilamiento y el escaneo del láser aéreo como otra herramienta adicimal enel arsenal de las medias láser de areo sensores remotos usados para detectar las codiciones de los patizales. Las medidas láser de aero de las propiedades del dosel de la planta sobre elterreno y los efutos aerodinamicos de la tosquedad de estas propiedades permiten un mejor entendimiento de las pérdidas de agua por evaporación, infltración y los movimientos de agua en la superficie. Las medidas con el láser nos permite comprender mejor el efecto del dosel de plantas y de las tosquedadas de la superficie en los pastizales.

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Stream change analysis using remote sensing and geographic information systems (GIS)

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Key Words: Time change analysis, remote sensing, Geographic Information Systems, GIS, stream morphology, large-scale aerial photography
http://uvalde.tamu.edu/jrm/remote/stream-paper.htm

Abstract

Remote sensing and Geographic Information Systems (GIS) are common tools for time change analysis, however, in most cases satellite imagery or small-scale aerial photography is used. The increased resolution of large-scale aerial photos helps in identifying small features on the ground and is highly useful in the assessment of riparian areas. In this project, large-scale aerial photography from 1979 and 1998, GIS, Global Positioning Systems (GPS) and ground truthing were combined in a time change analysis of an eastern Oregon riparian area. The objectives of this study were: 1) to examine changes in stream morphology over 20 years, 2) to assess if changes were associated with management, topography or other factors, 3) to determine the feasibility of using large-scale aerial photography, GIS and GPS techniques as a tool for assessing change over time.

The 2.5 km long study area, consisting of the stream and riparian area was separated into exclosures and grazed areas in 1978. Aerial photos from 1979 and 1998 (scale of 1:4000) were geo-referenced using 102 ground control points for the 41 ha study site. In addition, older aerial photography and previously collected survey data were available for this study. Stream features, such as islands and stream channel, were digitized using a GIS. Stream length, stream width and areas of change were identified for both years. The width of the stream was extracted automatically every 0.5 m along the 2.5 km long stream section, yielding 5070 width measurements. Although stream length remained the same over time, stream width decreased in both grazed and exclosed areas. The area of change (3.65 ha) was slightly larger than the area of no change (3.2 ha). Number of islands and island perimeter decreased, while the island area increased. Exclosures and grazed areas responded similarly, and it was concluded that the topography and stream dynamics had a greater impact than the grazing regime in this study. The use of large-scale aerial photography, GIS and GPS proved to be a powerful tool for detecting change and it is expected that these techniques will become more common in rangeland analysis in the future.

Resumen

La percepción remota y los Sistemas de Información Geográfica (SIG) son métodos comunes para análisis de cambio de tiempo, sin enbargo, en la mayoría de los casos, las imágenes satelitales o la fotografía aérea de esala pequeña es utils. La gran resolución de la fotografía aérea de escala grande ayuda identificacar características pequeñas en el suelo y es muy util en la evaluación de las áreas ribereñas. En este proyecto, la fotografía de escala grande de 1979 y 1998, el SIG, los Sistemas de Posicionamiento Global (GPS) y el ground truthing se utilizaron conjuntamente en un análisis de cambio de tiempo de un área ribereña del este de Oregón. Los objetivos de esta investigación fueron: 1) estudiar los cambios en la morfología de los arroyos durante veinte años; 2) evaluar si los cambios están relacionados con el manejo, la topografía o otros aspectos; 3) determinar la viabilidad de usar la fotografía aérea de escala grande, SIG y GPS como instrumentos para evaluar el cambio de tiempo. La área de estudio de 2.5km de largo impuesto de un arroyo y una parte ribereña, fueron separdad en cercamientos y áreas de pastoreo en 1978. Las fotos aéreas de 1979 y 1998 (escala de 1:4000) se georreferenciaron utilizando 102 puntos de control de territorio para las 41 ha. del sitio de investigación. Además, fotografías aéreas antiguas y datos recopilados anteriormente estaban disponsible para este estudio. Las características del arroyo, tales como las islas y arroyuelos, fueron digitalizados usando el SIG. Lo largo y ancho del arroyo y las áreas de cambio se identificaron para los dos años. El ancho del arroyo se extrajo automáticamente cada 0.5 m a lo largo del tramo de 2.5 km., produciendo 5070 medidas del ancho. Aunque la longitud del arroyo se mantuvo igual sobre el tiempo, el ancho del arroyo disminuyó tanto en los cercamientos como en las áreas de pastoreo. La área de cambio (3.65 ha.) fué un poco más grande que la área sin cambio (3.2 ha.) El número de islas y el perímetro de las islas disminuyó, mientras que la área de las islas aumentó. Los cercamientos y las áreas de pastoreo respondieron igualmente y se concluyó que la topografía y la dinámica del arroyo tuvieron un mayor impacto que el régimen de pastoreo en esta investigación. El uso de la fotografía aérea de escala grande, el SIG, y el GPS resultaron ser un método poderoso para detectar cambio de tiempo y se espera que en el futuro se vuelva más común el uso de tales técnicas en el análisis de los agostaderos.

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Responses of elk and mule deer to cattle in summer

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http://uvalde.tamu.edu/jrm/remote/auesursf.htm

Abstract

Cattle graze seasonally on national forests in the Western United States, and mule deer (*Odocoileus hemionus*) and/or elk (*Cervus elaphus*) are sympatric with cattle in most of these areas. But the effects of interspecific interactions in terms of both the resources selected and animal distributions across landscapes are poorly understood. At the USDA Forest Service Starkey Experimental Forest and Range (Starkey), located in northeast Oregon, USA, elk and mule deer were free ranging within a 78 km^2 study area enclosed by a 2.4 m high fence while cattle were moved among pastures in summer on a deferred-rotation schedule. Elk, mule deer, and cattle were located with an automated telemetry system from 1993–1996 and locations linked to a geographic information system (GIS) of Starkey. Our objective was to examine responses of elk and mule deer to cattle at multiple spatial and temporal levels. We compared elk and mule deer distributions, use of plant communities, and resource selection functions in one cattle pasture (24 km^2) during early summer (cattle present in odd-numbered years) and late summer (cattle present in even-numbered years). Elk and deer differed in their spatial and temporal responses to presence of cattle. When cattle were present, the proportion of elk locations within the pasture decreased and use of the ponderosa pine/Douglas fir (*Pinus ponderosa/Pseudotsuga menziesii)* plant community within the pasture decreased in early summer and increased in late summer. The cattle resource selection function variable for early summer was not a predictor of elk distributions when cattle were present, but it was a predictor on years when cattle were absent. In late summer, the cattle resource selection function variable was a predictor of elk distributions regardless of presence of cattle. For mule deer distributions the cattle resource selection function variable was not a significant predictor in early summer (cattle present or absent), or in late summer when cattle were present, but it was a negative predictor of mule deer distributions when cattle were absent in late summer. Mule deer use increased or decreased in opposite direction from elk use in 3 of 4 season/year combinations for both pasture and ponderosa pine/Douglas fir. Our results suggest that competition for forage could occur between elk and cattle in late summer and that species interactions may be stronger between elk and cattle than mule deer and cattle. We recommend that managers look closely at stocking levels in late summer because cattle and elk use some of the same resources during that period, and to pay particular attention to the ponderosa pine/Douglas fir plant community where we found significant interactions between cattle and elk.

Resumen

En la mayoría de las áreas en el oeste de los Estados Unidos, el apacentamiento de ganados ocurre simultáneamente con los venados (*Odocoileus hemionus*) y los alces (*Cervus elaphus*). Pero las interacciones interespecificas en términos de recursos seleccionados y las distribuciones de los animales en el medio ambiente no esta muy claramente entendido. En el USDA Forest Service Starkey Experimental Forest and Range (Starkey), localizado en el noroeste de Oregon, EEUU, alces y venado apacentan libremente en un área de estudio de 78 km^2 cuadrados encerrados por una cerca de 2.4 m de alto. El ganado es transferido entre pastos durante el verano en un itinerario de rotación deferida (deferred-rotation schedule). Los alces, vendados, y ganado fueron localizados con el uso de sistema de telemetría automatizada desde el 1993-1996 y las localidades fueron conectadas al sistema de información geográfica (GIS) de Starkey. Nuestro objetivo fue para examinar las reacción de los alces, venados, y ganado en varios niveles espaciales y temporales. Nosotros comparamos la distribución de alces y venados, el uso de vegetación, y la selección de recursos en un pasto de ganado (24 km^2) durante la primera parte del verano (ganado presente en años nones) y durante la segunda parte del verano (ganado presente en años pares). Los alces y los venados respondieron diferentemente en sus reacciones temporales y espaciales en la presencia de ganado. Cuando el ganado está presente, la proporción de locaciones de alces fue reducida y el uso de pino ponderosa/Douglas fir (*Pinus ponderosa/Pseudotsuga menziesii*) el pasto se redució en el comienzo del verano y aumento en el final del verano. La función variable de selección de recursos del ganado para la primera parte del verano no fue predictor de la distribución de alces cuando el ganado estuvo presente, pero fue predictor en años cuando el ganado estuvo ausente. En la parte tarde del verano, la función variable de selección de recursos fue predicador de la distribución de alces sin tener cuenta de la presencia de ganado. Para la distribución de venado (mule deer), la función variable de selección de recursos no predijo significantemente en la primera parte del verano (ganado presente o ausente), o en la parte tarde del verano cuando el ganado estuvo presente. Pero fue un predictador negativo en la distribución de venados cuando el ganado estuvo ausente en la parte tarde del verano. El uso del venado aumento o redució en la dirección opuesta al uso del alce en 3 de 4 combinaciones de estación/año para ambos pastos y pino ponderosa/Douglas fir. Nuestros resultados indican que la competencia por forraje entre alce y ganado ocurren en la parte tarde del verano y que las interacciones entre estas especies son mas fuertes entre alce y ganado que entre el venado y el ganado. Nosotros recomendamos que los gerentes miren atentamente los niveles de abastecimiento en la parte tarde del verano porque el ganado y los alces usan algunos de los mismos recursos durante este periodo, y deben prestar particularmente atención a la comunidad de pino ponderosa/Douglas fir donde nosotros encontramos interacciones significantes entre los alces y los ganados.

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Remote sensing of range production and utilization

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http://uvalde.tamu.edu/jrm/remote/srmremsens.htm

Abstract

Remote sensing has been used in range management primarily as a tool to map various rangeland ecosystems or plant communities. Efforts have focused on using both photo interpretation and image processing or a combination of the two to accomplish this. The determination of range production and utilization is basically a classification problem. Since range management is a land based science, we are concerned with the distribution of information across landscapes. The need is to identify and map areas of differences in forage production over time to describe the different levels of utilization so that the data might be useful to managers. Production of forage is best defined as the increment of new biomass over time during a growing season. This is a difficult problem because of the need to examine the numerous species including both herbaceous forage and browse, both in the open and under forest canopies. In fact, at the present time it may not be possible to do this with any high degree of accuracy. However, there is potential that remote sensing and information systems offer considerable hope for the future. The amount of this forage harvest over time (utilization) is, in many ways, the sine qua non of range management. This paper is a review of the literature and possibly some new ideas on how we might classify landscapes as to the level of forage production and the amount removed or harvested over some period of time using remotely sensed data.

Resumen

Monitoreo remoto ha sido usado en cierta mancra como una herramienta principal para trazar varios ecosistemas de praderas y comunidades de plantas. Losesfuerzos se han enfocado en el uso de la interpretacion de fotos, asi como elementos. La determinacion del rango de produccion y la utilizacion de esta es basicamente un problema de clasificacion. La manera en que se distribuyen o se alincan los surco de tierra se basa en la composicion cientifica de la tierra, esto por lo tanto, crea el problema de distribucion de information a traves de los paisajes. La necesidad consiste en la identifiacion y en el trazo de las diferencias que existen en las areas, las cuales permiten una produccion de forraje a traves del tiempo y que a su vez sirve para describir los diferentes niveles de uso. La produccion de forraje se define como el incremento. Esto es un problema muy dificil que implica la neccsidad de examinar numerosas especies de forraje herbaceo y pastura, las cuales se hayan en campo abierto y bajo la copa forestal. Es importante tomar en cuenta que esto en la actualidad no puede ser posible cualquiera que sea el grando de exactitud. Sin embargo, es posible que el monitoreo remoto y los sistemas de informacion ofrezcan unaesperanza alentadora en el futuro. La cantidad de cosecha del forraje a traves del tiempo, es en muchas maneras el sine qua non del manejo y distribucion del campo. Este trabajo es una revision de articulos escritos en este campo asi como podriamos clasificar los paisajes, el nivel de produccion de forrajc y la cantidad de cosecha buena y la que se desecha: todo esto a traves de un cierto periodo de tiempo tomando en cuenta el uso de informacion de monitoreo remoto.

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Mapping weekly rangeland vegetation productivity using MODIS algorithms

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http://uvalde.tamu.edu/jrm/remote/srm_modis_mapping htm

Abstract

The great spatial extent of rangelands combined with recent emphasis on rangeland health has prompted a need for more efficient and cost effective management tools. The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor of the Earth Observing System (EOS) will offer improved and more timely monitoring of rangeland vegetation, and, unlike any previous satellite sensor, the publicly available MODIS data stream will include estimates of rangeland productivity. These estimations of rangeland productivity can be used regionally for measuring biomass production and will be available every eight-days, with global coverage at 1-km^2 resolution. MODIS derived estimates of rangeland productivity combine remote sensing information with daily meteorological data as inputs to a mathematical model of photosynthetic conversion of solar radiation into plant carbohydrates. Vegetation productivity is a measure of rangeland vegetation vigor and growth capacity, which are important components of rangeland management and health assessment. Using MODIS data, it will be possible to characterize rangeland vegetation seasonality, estimate herbage quantity and, monitor the rates and trends of change in primary production. Consistent, objective and frequent productivity estimates will be available for even the most inaccessible rangelands.

Potential applications of weekly and annual productivity estimates are demonstrated on the Shoshone BLM Administrative District and a larger portion of the Interior Northwestern United States. Productivity estimates were derived using Advanced Very High-Resolution Radiometer data as a surrogate for the MODIS data stream. Shrub and grassland vegetation seasonality for 1991 was characterized. Herbage quantity was estimated from the 1993 shrub and grassland regional net primary production. A 5-year average productivity from 1990–1994 and departures from that average were calculated for the years 1991 and 1993. The measures of departure indicated that 1991 was regionally less productive and 1993 more productive than the five year average.

Collaboration between rangeland scientists and managers is necessary to realize the potential for EOS-derived vegetation productivity as a management tool. Future research will include field calibration of the productivity algorithms and exploration of new techniques for using EOS-derived productivity measures for rangeland management. Measures of rangeland productivity could become part of an integrated rangeland system analysis. This may permit differentiation between anthropogenic, biotic, and abiotic factors as the primary cause of declining productivity. Other research may include customization of biome properties for selected regions.

Resumen

La gran extensión espacial magnífica de los agostaderos combinado con el recienteénfasis en la salud de agostadero ha incitado una necesidad para más eficiente y costó herramientas efectivas de administración. El sensor Moderado de Spectroradiometer (MODIS) de la Resolución Imaging del Sistema (EOS) de Observar de Tierra ofrecerá mejor control y más oportuno de vegetación del agostadero, y, a diferencia de sensor previo de satélite, la corriente públicamente disponible de datos de MODIS incluirá las estimaciones de productividad de agostadero. Estas estimaciones de productividad del agostadero se pueden usar regionalmente para medir la producción de biomass y estar disponible para cada ocho días, con el alcance global en la resolución 1-km^2. MODIS derivó las estimaciones de productividad de agostadero combinan información remota que presiente con datos diarios de meteorological como entradas a un modelo matemático de la conversión de photosintetico de la radiación solar en carbohidratos de planta. Productividad de vegetación es una medida del vigor del agostadero y capacidad de crecimiento, que es los componentes importantes de la administración de agostadero y evaluación de salud. Usando los datos de MODIS, será posible en caracterizar la vegetación de agostadero en tiempo oportunos, la cantidad de herbage de estimación y, controla las tasas y las tendencias del cambio en la producción primaria. Sólido, el objetivo y frecuenta las estimaciones de productividad estarán disponible para aún agostadero más inaccesible. Las aplicaciones potenciales de estimaciones semanales y anuales de productividad se demuestran en el Shoshone BLM el Distrito Administrativo y una porción más grande de los Estados Unidos del noroeste Interiores. Las estimaciones de productividad se derivaron usando los datos Muy de la Resolución Alta Avanzados de Radiometer como un sustituto para la corriente de datos de MODIS. El arbusto y seasonality de vegetación de prado para 1991 fueron caracterizados. La cantidad de Herbage se estimó del 1993 arbusto y el prado la producción primaria, neta y regional. Una productividad mediana de 5 años de 1990 – 1994 y las salidas de que promedia fueron calculados por los años 1991 y 1993. Las medidas de la salida indicaron que 1991 eran regionalmente menos productivos y 1993 más productivo que el cinco promedio de año. La colaboración entre científicos de agostaderos y manejadoress es necesario a para vocalizar la portencia de la productividad derivada de EOS como una herramienta de administración. Investigaciónes en el futuro incluirá la calibración de campo de los algoritmos de productividad y exploración de técnicas nuevas para usar las medidas derivadas de EOS de productividad para la administración de agostaderos. Las medidas de productividad de agostadero podrían llegar a ser la partes de un análisis integrado de sistema de agostadero. Esto puede permitir la diferenciación entre anthropogenic, biotico, y los factores de abiotico como la causa primaria de productividad declinante. Otra investigación puede incluir customization de propiedades de biomio para regiones escogidas.

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Reflectance and image characteristics of selected noxious rangeland species

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http://uvalde.tamu.edu/jrm/remote/boise.htm

Abstract

This paper demonstrates the use of field reflectance measurements and aerial photography (color-infrared and conventional color) for distinguishing noxious plant species on rangelands. The visible/near-infrared (0.45–0.90 µm) reflectance characteristics of several brush and weed species found on rangelands in the U.S. and Mexico are presented. The phenological stage of plants has an important influence on their spectral characteristics and subsequent detection on aerial photographs. Canopy architecture, vegetative density, and leaf pubescence are also important for distinguishing some species. Reflectance measurements are related to the plant species color tonal responses on CIR and CC photographs. Plant species addressed include silverleaf sunflower (*Helianthus argophyllus* Torr. and Gray), broom snakeweed [*Gutierrezia sarothrae* (Pursh.) Britt. and Rusby], huisache [*Acacia smallii* (L.) Willd.], Big Bend locoweed [*Astragalus mollissimus* var. earlei (Rydb.) Tidestr.], Wooton locoweed (*Astragalus wootonii* Sheld.), and Chinese tamarisk (*Tamarix chinensis* Lour.).

Resumen

Este documento demuestra el uso de las medidas de reflexión de campo y de la fotographía aérea [color-infarrojo (CIR) y color convencional (CC)] para distinguir especies de plantas nocivas en los pastizales. Se presentan las caracteristicas de reflexión visibles (póximas a infrarrojo, 0.45-0.90 m m) de varias especies de arbustos y maleza encontrados en los pastizales en E.U. y México. La etapa fenológica de las plantas tiene una influencia importante sobre sus caracteristicas espectrales y su detección subsecuente mediante la fotografía aérea. La arquitectura del dosel de plantas, la densidad de la vegetación y el desarrollo de la hoja, son también factores importantes para distinguir algunas especies. El tono del color, de algunas especies de plantas presentadas en la fotografía CIR y CC, están relacionadas con las medias de reflexión. Las especies de plantas citadas incluyen: girasol silvestre (*Helianthus argophluss* Torr. y Gray); escobilla de bruja [*Gutierrezia sarothrae* (Pursh.) Britt. Y Rusby]; huisache [*Acacia smallii* (L.) Willd]; Big Bend locoweed [*Astragalus mollissimus* var. earlei (Rydb.) Tidestr.]; Wooton locoweed (*Astragalus wootonii* Sheld.); y tamarisk chino (*Tamarix chinesis* Lour.).

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