Agrociencia

TRADITIONAL AND UPDATED EVALUATION OF THE RANGELAND SITE AND CONDITION IN THE SEMIARID SCRUB OF THE HIGH PLATEAU

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ABSTRACT

In Mexico, the concepts of rangeland site and condition are not well known. For this reason, most of the rangelands of private ranches on the high plateau of San Luis Potosí and Zacatecas are undergoing a process of severe generalized deterioration. The purpose of this study was to survey and characterize multi-branched rangeland sites of three beef cattle ranches on the San Luis Potosí-Zacatecas High Plateau, as well as to assess their condition using a quantitative ecological method complemented by updated technological tools. The hypothesis proposed was that the site and condition of rangeland evaluated with the quantitative ecological method (used for grasslands and soil), complemented by updated technology, are also identifiable in multi-branched rangelands of this type of production units on the San Luis Potosí-Zacatecas High Plateau. Based on a Landsat satellite image, an unsupervised classification process was performed for the three ranches, which was then confirmed by field observations. A total of 11 sites were surveyed, three on each ranch (microphyll desert scrub, predominantly *Bouteloua gracilis*; microphyll desert scrub, with predominance of *Sporobolus airoides*; and an ecotone between microphyll desert scrub and rosetophile desert scrub) and two exclusive locations (crassicaule scrub and rosetophile desert scrub with predominance of *Muhlenbergia villiflora)*. Rangeland condition was evaluated by measuring density and volume (volumetric biomass) of the main plant species, categorized by forage value, and the actual state of the soil surface was assessed in terms of bare soil and vegetation, litter, feces and rock cover. The data were ordered and classified with the DECORANA and TWINSPAN modules from the PC-ORD program. Site and condition evaluation under this approach was satisfactory for surveying the state of the rangelands of the three private cattle ranches studied on the San Luis Potosí-Zacatecas High Plateau.

Keywords: multivariate analysis, cattle in scrub vegetation, supervised classification, soil cover, rangeland site.

Citation: Aguirre-Rivera JR, Negrete-Sánchez LO, Castro-Rivera R. 2023. Traditional and updated evaluation of the rangeland site and condition in the semiarid scrub of the high plateau.
Agrociencia https://doi.org/ 10.47163/agrociencia.v57i3.2620

Editor in Chief:
Dr. Fernando C. Gómez Merino

Received: February 18, 2022.
Approved: February 08, 2023.
Published in Agrociencia:
March 30, 2023.

INTRODUCTION

Half of the world's land area is covered by rangeland (Holechek *et al.*, 2011). In San Luis Potosí, more than 1.6 million ha are designated as rangeland (INEGI, 2007), which is mainly used for grazing livestock that feed on spontaneous vegetation (CONAZA, 1994). Grazing causes alterations in the vegetation, similar to those caused by other human activities (Lasanta, 2010). Rangelands are a natural resource that, when used rationally, can be productive and environmentally stable indefinitely (Holechek, 1991). However, rangeland abuse on the High Plateau in the states of San Luis Potosí and Zacatecas, Mexico, is evident, and the death of the livestock that occurs during droughts is, to date, the only remedy for their seasonal recovery. Therefore, the derived unconscious process of desertification occurs and is generalized while the organic production potential of these lands decreases gradually and irreversibly (Negrete-Sánchez *et al*., 2016).

Currently, extensive grazing on rangelands is the primary mode of beef production (Ruechel, 2012). Techniques for evaluating the potential, condition, and trend of rangelands, whose definition and procedure were developed during the first half of the last century, particularly for the climactic grasslands of North America, have been developed for the use of rangelands with an ecological basis. (Dyksterhuis, 1949). Holechek *et al*. (2011) defined a rangeland site as a landscape unit resulting from the combination of biotic and abiotic factors of the environment, which together determine primary production.

The condition of a rangeland is estimated to characterize the actual state of its botanical composition in relation to climax vegetation. Under this approach, it is classified into four categories: poor, regular, good, and excellent, depending on the relative importance of the species present, their forage value, and their response to grazing (Dyksterhuis, 1949). Humphrey (1949) defined condition as the amount of forage produced in relation to the site's maximum potential. However, Holechek *et al*. (2011) proposed that rangeland site condition should be determined by combining structural and functional vegetation and soil state or cover variables. The trend of the rangeland is the probable direction of the condition based on the succession of species, which can determine a progressive change toward improvement of the rangeland, regression because of deterioration, stability if no change is reflected, or divergence if one part improves but another regresses. This methodology has been applied to all public and private grass-covered rangelands in the southwestern USA (USDA, 2013).

In Mexico, only in the 1960s was an attempt made to apply these rangeland evaluation techniques to other vegetation types, ranging from grasslands to scrub vegetation, forests, and jungles (COTECOCA, 1974). Although current mean stocking rates on most of the private ranches in Mexico can be considered excessive, some ranchers maintain moderate rates with relevant results in terms of reproduction and production indicators of their herds (CONAZA, 1994). On some of these ranches there are visual differences, from subtle to marked (Figure 1), in the vegetation structure and state of the soil surface.

Figure 1. A: private rangeland, Rancho San José, Villa de Cos, Zacatecas, in good condition, a microphyll desert scrub site with *Sporobolus airoides* dominance; B: communal rangeland, ejido Noria de Gutiérrez, Charcas, San Luis Potosí, in poor condition (image captured with a drone on October 6th, 2022, during the wet season of the year).

The virtues of multivariate analysis for rangeland classification using condition gradients were highlighted by Bolaños-Medina and Aguirre-Rivera (2000) and Aguirre-Rivera *et al*. (2020). Although this technique has received little attention in rangeland research, it has been used in other studies to identify gradients of morphological variations in domesticated prickly pear by Reyes-Agüero *et al*. (2005) and in the *Salmianae* group of the *Agave* genus by Mora-López *et al.* (2011). Regarding the use of satellite images, Medina *et al.* (2009) and Easdale *et al*. (2019) used SPOT and VANT images to identify rangeland sites to estimate forage production by means of an unsupervised classification process and a normalized difference vegetation index, respectively.

Based on the above, the objective of this study was to apply published local information to distinguish and characterize multi-branched rangeland sites (comprising herbs, grasses, and woody plants) and to evaluate their condition using the quantitative ecological method complemented by updated technological tools on three beef cattle ranches on the High Plateau in the states of San Luis Potosí and Zacatecas. The postulated hypothesis was that the sites and conditions of the rangeland evaluated by the quantitative ecological method (used for grasslands and soil), complemented with updated technology, are also identifiable in the multi-branched rangelands of private ranches on the San Luis Potosí-Zacatecas High Plateau.

MATERIALS AND METHODS

General aspects of the studied ranches

The three privately owned ranches found in the states of San Luis Potosi and Zacatecas in the southern part of the Chihuahuan Desert are part of the geomorphological region known as the Northern Mexican Highplain (Tamayo, 2012). These ranches have deep wells, pumps, and water reservoirs (runoff deposits), with which they have established networks of watering holes. They also have roads, handling corrals, border fences and paddocks, salt blocks, etc. The physical description of the study area is based on INEGI (2017) thematic maps. The geological substrate in San José (SJ) and El Porvenir (EP) is Quaternary, Tertiary, and Lower Cretaceous sedimentary rock. Laguna Seca (LS) also has a Triassic shale-sandstone sedimentary substrate and Tertiary acid extrusive igneous rock tuffs.

All three ranches are located in the hydrologic region “El Salado”. The dominant soil in the three ranches is Haplic xerosol, and the secondary soil is lithosol, of medium texture in the petrocalcic phase. In LS there are also rendzinas, lithosols, and calcaric regosols of medium texture in the lithic phase, while in SJ there are calcaric regosols and lithosols of medium texture in the lithic phase. The climate in LS is $BS_0kw(x')$, while in SJ and EP it is BS_0kw. The dry season in the three ranches lasts approximately seven months (SMN, 2021). The vegetation types present in the three ranches are microphyll desert scrub and, in a smaller proportion, rosetophile desert scrub. Moreover, in LS there are areas with crassicaule scrub in the igneous outcrops.

Characterization of the vegetation

Based on LANDSAT satellite images from February 2017, unsupervised classification in ARC GIS® v.10 began in September of the same year, with five classes of cover, to identify the different types of vegetation that exist on each of the three ranches. Later, variants of the vegetation of interest to the study were identified in the field. Two of the cover classes in each ranch were discarded since one was rosetophile desert scrub in steep mountainous areas inaccessible for cattle and the other included areas with bare soil (roads).

On the three ranches, there were three corresponding vegetation variants: the ecotone between microphyll desert scrub and rosetophile desert scrub (*MDS-RDS*), and two variants of microphyll desert scrub, one with a predominance of *Bouteloua gracilis (MDSBG)* and the other with a predominance of *Sporobolus airoides (MDSSA).* Moreover, in EP there was another variant of microphyll desert scrub with a predominance of *Muhlenbergia villiflora (MDSMV)*, and only in LS was crassicaule scrub (*CS*) recorded. These vegetation types and characteristics of the Chihuahuan Desert can be considered rangeland sites, according to the corresponding definition (Holechek *et al*., 2011). In each of the 11 sites, perennial species were collected. Although they were part of the initial serial states, annual species were discarded because they lack significant effects on rangeland productivity since their presence is ephemeral. The collected specimens were identified and deposited in the herbarium Isidro Palacios (SLPM) of the Desert Zones Research Institute of the *Universidad Autónoma de San Luis Potosí*.

Structural measurements of the vegetation

The thematic maps and plots generated with unsupervised classification, together with field observations in August and September 2018 (second half of the rainy, or growing, season), enabled the placement of two sampling areas in each of the surveyed rangeland sites. The method of quadrants without plots centered on points along transects (Cottam and Curtis, 1956) was used with the adequacy developed by Aldrete-Menchaca and Aguirre-Rivera (1982) for use in multi-stratified vegetation. The transects were defined with a 100 m long nylon cord stretched between steel stakes. The location of the transects was always at least 50 m from any fence, in the central part of the physiognomy of the surveyed site, and perpendicular to the slope. The initial and final points of each transect were georeferenced to make later evaluations possible. At every 20 m of the transect, a 10 m cord was installed perpendicularly to form four quadrants.

Before starting the measurements, the transect surroundings were searched for specimens, and a list of the most abundant perennial plant species in each of the four strata surveyed in these scrub vegetations was made: herbaceous, low shrubs, tall shrubs, and arborescent plants. The rest of the perennial species observed in the rangeland were recorded and collected to include them in a complete botanical list. In each quadrant, the distance from the point on the transect to the base of the closest plant was measured, and besides its species and distance, its basal diameter, upper diameter, and height were registered. This process was carried out in sequence by stratum, beginning with the herbaceous stratum, which was the densest and most susceptible to damage from trampling, and followed by each of the remaining strata.

For tussocky plants clumped in colonies, the distance from the point to the center of the set was measured, and for the rest of the plants, the distance to the basal part closest to the transect point was measured (Aldrete-Menchaca and Aguirre-Rivera, 1982). In the case of very large izotes, mesquites, and huisaches, height was determined with a clinometer. The plant species sampled were classified as desirable, less desirable, and undesirable based on their forage value and successional response to grazing. (Valentine, 1990). To calculate the density of each species, the reciprocal of the square of the mean distance of the species (measured area of the species) with the following formula:

$$\text{Density of species } i = \frac{\text{unit of area}}{\text{mean distance}^2 \text{ of species } i}$$

where the term 'unit of area' is the area of reference to express the density in the same units as the mean area of the species.

To estimate instantaneous biomass volume of each individual, the formula of the inverted truncated cone was used:

$$V = 1/3\, \pi h\, (R^2 + r^2 + Rr)$$

where π = 3.1416; h= height or distance between the two radii; R= top or expansion radius, and r= basal radius.

State of the soil surface

The state of the soil surface in each survey was estimated using five Canfield interception lines (Canfield, 1941), each one 5 m long, installed parallel and alternately to the main transect. The beginning and ends of these lines were also georeferenced. Along these lines, portions of bare soil and those with vegetation cover, litter, rocks, or feces were measured. The mean values of these components expressed in centimeters were summarized and arranged in tabular form.

With the data on vegetation and soil cover (13 variables) of the 11 rangeland sites studied on the three ranches, a 13 x 11 matrix was formed (Table 1), with which multivariate analysis programs were processed with PC-ORD v. 6 software (McCune and Mefford, 2011), specifically with the DECORANA (Detrended Correspondence Analysis) module to order vegetation and soil variables and with TWINSPAN (Two-way indicator species analysis) to classify the rangeland sites.

RESULTS AND DISCUSSION

Part of the method used in this study to determine rangeland condition coincides with that used by Contreras *et al.* (2003), who used Canfield lines to evaluate the condition of the communal rangelands of Yanhuitlán, Oaxaca. Also, some of the variables evaluated in our study coincide with those applied by Solomon *et al.* (2007) in their study of the perception of degradation of the rangelands in southern Borana, Ethiopia; the principal indicators of deterioration were a decrease in abundance of desirable Poaceae, an increase in undesirable woody species, and an increase in the portion of bare soil.

Table 1. Variables included in the multivariate analysis of the studied rangeland.

Variable	Acronym
Total perennial species measured	TOTAESPE
Total perennial species present	TOTESPRE
Density of desirable species	DENSDESE
Density of less desirable species	DENSMENO
Density of undesirable species	DENSINDE
Biomass of desirable species	BIOMDESE
Biomass of less desirable species	BIOMMENO
Biomass of undesirable species	BIOMINDE
Bare soil	SUELDESN
Soil covered with litter	SUELMANT
Soil covered with vegetation	SUELVEGE
Soil covered with feces	SUELHECE
Soil covered with rocks	SUELPIED
Ecotone *MDS-RDA* Laguna Seca	LSMDMMDR
Ecotone *MDA-RDA* San José	SJMDMMDR
Ecotone *MDS-RDS* El Porvenir	EPMDMMDR
MDS with predominance of *Bouteloua gracilis* San José	SJMDMBG
MDS with predominance of *Bouteloua gracilis* El Porvenir	EPMDMBG
MDS with predominance of *Bouteloua gracilis* Laguna Seca	LSMDMBG
MDS with predominance of *Muhlenbergia villiflora* El Porvenir	EPMDMMV
MDS with predominance of *Sporobolus airoides* Laguna Seca	LSMDMSA
MDS with predominance of *Sporobolus airoides* San José	SJMDMSA
MDS with predominance of *Sporobolus airoides* El Porvenir	EPMDMSA
CS Laguna Seca	LSMATCRA

Lara-Juárez *et al.* (2016) used the same technique to evaluate rangeland condition in another study to determine the relationship between rangeland condition and the presence of escamole ant nests (*Liometopum apiculatum*) in a rangeland shared by a private ranch and an adjacent ejido in Charcas, San Luis Potosí, although they only classified rangeland condition qualitatively as better, worse, and intermediate. Mellink and Valenzuela (1995) used the concept of rangeland condition qualitatively as well, categorizing their findings as better or worse.

Characterization of vegetation

The density (individuals ha^{-1}) and instantaneous biomass volume (m^3 ha^{-1}) of the main perennial species were estimated in four rangeland sites: LS (with 112 sampling points), SJ (with 120 sampling points), and EP (with 108 sampling points), for a total of 340 sampling points, equivalent to 1360 quadrants and 3996 individuals of plant species measured. During the study survey, 12 preponderant species were measured and identified in LS, 16 in SJ, and 12 in EP (Table 2). Moreover, outside the sampled areas, another 36 perennial species were observed in LS, 25 in SJ, and 28 in EP, to complete a floristic list: 48 perennial species in LS, 41 in SJ, and 40 in EP.

Table 2. Species recorded and their forage value in the rangeland sites studied on the Laguna Seca (1), San José (2) and El Porvenir (3) ranches.

Species	Stratum†				VF¶	Ranch
	A	B	C	D		
Acacia schaffneri (S. Watson) F.J. Herm.				x	M	1, 2
Agave salmiana Otto ex Salm.			x		M	1
Bouteloua curtipendula (Michx.) Torr.	x				D	1
Bouteloua gracilis (Willd. ex Kunth) Lag. ex Griffiths	x				D	1, 2, 3
Calliandra eriophylla Benth		x			D	1
Celtis pallida Torrey			x		I	1
Condalia mexicana Schltdl.			x		I	2
Cylindropuntia imbricata (Haw.) F.M. Knuth			x		I	2
Dalea bicolor Humb. & Bonpl. ex Willd.		x			D	1
Dasyochloa pulchella (Kunth) Willd. ex Rydb.	x				M	2, 3
Erioneuron avenaceum (Kunth) Tateoka	x				D	3
Flourensia cernua DC.			x		I	3
Larrea tridentata (Sessé & Moc. ex DC.) Cov.			x		I	1, 2, 3
Lycurus phleoides Kunth	x				M	1
Mimosa biuncifera Benth			x		I	2
Muhlenbergia villiflora Hitchc.	x				D	3
Opuntia cantabrigiensis Lynch			x		M	1, 2, 3
Opuntia rastrera F.A.C.Weber		x			M	1, 2, 3
Parthenium argentatum A. Gray		x			D	2, 3
Parthenium incanum Kunth		x			D	3
Sporobolus airoides (Torrey) Torrey	x				D	1, 2, 3
Yucca filifera Chabaud				x	M	2, 3

†Strata: A: herbaceous; B: low shrubs; C: tall shrubs, D: arborescent. ¶Forage value for cattle. D: desirable; M: less desirable; I: undesirable.

The total floristic composition recorded on the three ranches of this study (Table 2) was generally qualitatively and quantitatively similar to that described by diverse authors for the vegetation in analogous environmental conditions (Rzedowski 1957; Bikila and Tessema, 2017; Aguirre-Rivera *et al.*, 2020). Pinos-Rodríguez *et al.* (2013) also recorded 38 species consumed by goats in communal rangelands of Villa de Guadalupe, San Luis Potosí, while Lara-Juárez *et al.* (2016), in their study of escamole ants, found 35 species in the "Siete Vueltas" paddock of the LS ranch and only 22 in the ejido Francisco I. Madero. The two properties were separated by a borderline fence and shared the same rangeland sites, and sampling was based on the same sample size. The difference observed was an indicator of the degradation of communal rangelands due to severe generalized overgrazing with no individual limits on stocking rate (Lara-Juárez *et al.*, 2016; Negrete-Sánchez *et al.*, 2016), as compared with private ranches where the owners can more easily make decisions to adjust stocking rate and spatial distribution.

Differences in vegetation structure caused by paddock use patterns in the same rangeland site

Unlike other studies that evaluated rangelands but did not indicate the vegetation classes found (Contreras *et al.,* 2003; Solomon *et al.*, 2007; Bikila and Tessema, 2017), in our study, we described in detail the rangeland sites present on the three ranches to evaluate and determine their condition.

The three ranches have three coinciding rangeland sites: *MDS-RDS, MDSBG,* and *MDSSA*; moreover, in LS, we registered *CS* and *MDSMV* in EP (Table 3). When the condition of the identified rangeland sites was considered, the results were particularly different. In LS, density and biomass of desirable species were significantly higher in two (MDS-RDS and MDSBG) of the three rangeland sites shared by the three ranches; this was more pronounced with density values than with biomass values. The opposite occurred in the third common rangeland site (MDSSA), as the lowest values were

Table 3. Density (thousands of individuals ha^{-1}) and mean weighted biomass volume (thousands of m^3 ha^{-1}) of the species grouped according to their forage value on the three studied ranches†.

Site	Density			Biomass		
Forage value	LS	SJ	EP	LS	SJ	EP
MDS-RDS						
Desirable	456.9	13.3	25.4	1.9	0.2	1.6
Less desirable	2.4	25.3	15.6	4.8	2.0	0.1
Undesirable	1.0	3.7	0.5	0.7	1.0	0.1
Total	460.3	42.3	41.5	7.4	3.2	1.8
MDSBG						
Desirable	160.9	31.8	36.7	7.3	1.5	0.3
Less desirable	1.5	35.5	0.0	1.0	1.8	0.0
Undesirable	1.7	1.6	2.9	1.6	1.0	2.5
Total	164.1	68.9	39.6	9.9	4.3	2.8
MDSSA						
Desirable	4.0	35.0	313.0	2.0	2.4	30.7
Less desirable	0.8	86.0	43.2	3.9	0.7	3.4
Undesirable	0.0	1.1	7.8	0.0	0.9	2.9
Total	4.8	122.1	364.0	5.9	4.0	37.0
CS						
Desirable	741.0	0.0	0.0	3.5	0.0	0.0
Less desirable	0.7	0.0	0.0	1.1	0.0	0.0
Undesirable	0.0	0.0	0.0	0.0	0.0	0.0
Total	741.7	0.0	0.0	4.6	0.0	0.0
MDSMV						
Desirable	0.0	0.0	35.4	0.0	0.0	0.4
Less desirable	0.0	0.0	0.0	0.0	0.0	0.0
Undesirable	0.0	0.0	9.9	0.0	0.0	1.6
Total	0.0	0.0	45.3	0.0	0.0	2.0

†LS: Laguna Seca; SJ: San José; EP: El Porvenir.

recorded in LS, while the opposite occurred noticeably in EP for both density and biomass.

It should be noted that, of the three sites mentioned, and for both attributes of the evaluated vegetation, the least desirable species predominated in SJ, indicating the ranch's poor condition. Desirable species predominated at the MC site of LS, and the absence of undesirable species was notable, as it was at other ranch sites. The MDSMV site, found only in EP, and the MDSBG site of the same ranch were the only ones where biomass of undesirable species predominated, indicating the ranches' poorest condition.

Surveying and location of possible rangeland sites on satellite images can be done without major difficulties because of the existence of cartographic antecedents and the physiognomic, floristic and habitat descriptions of the main regional vegetation types, as well as the corresponding thematic cartography that enables establishing their relationship with relief, soil variants and geological origin (Aguirre-Rivera *et al*., 2020). Rzedowski (1957) described crassicaule scrub as linked to soils of igneous origin, Rosetophile desert scrub as typical of hilly terrain of sedimentary origin, microphyll desert scrub as typical of limestone alluvial plains and grasslands common to the plains, and the transitions or ecotones between them, sometimes gradual and very extensive, and sometimes very marked and in little space, depending on the substratum and relief.

The differences in density and biomass recorded among the three rangeland sites present on the three ranches (Table 3) are attributable to notable differences in the pattern of use of the forage resource imposed by their owners, such as stocking rate and its spatial distribution (Holechek *et al*., 2003). Lara-Juárez *et al*. (2016) surveyed three different sites in a single paddock in LS where the livestock had caused different impacts, evidenced by contrasts between groups of desirable species. Indeed, the differences in the pattern were clearly reflected in our study by the relative importance of species with different forage values and by the state of the corresponding soil surface (Table 4). None of the three ranches was exempt from deficiencies in their rangeland management, although LS stood out with the best soil surface state, the largest proportion of desirable species in three of its four sites, and the absence of undesirable species in the paddocks of its *MDSSA* site, denoting more abuse on the other two ranches at the same site.

The growing problem of rangeland deterioration in arid regions was also recognized by Lara-Juárez *et al*. (2016) and Bikila and Tessema (2017). Grouping the species registered during the surveys according to the forage value and scoring them based on the literature, direct observation, and opinions of local people was suitable for determining structural changes in the vegetation due to use patterns and in accordance with relevant antecedents for similar conditions (Solomon *et al*., 2007; Lara-Juárez *et al*., 2016; Bikila and Tessema, 2017; Aguirre-Rivera *et al*., 2020) and, in general, for grazing spontaneous vegetation.

Regarding the evaluated structural attributes, density seemed to be more sensitive to slow relative changes associated with condition, particularly because biomass can be

Table 4. Mean soil surface cover (cm) in rangeland sites of three private ranches (n = five 500 m Canfield lines).

Ranch Site	Cover					
	Bare soil	*Litter*	*Vegetation*	*Rocks*	*Feces*	Total
LS						
MDS-RDS	92.8	27.7	324.4	33.3	21.8	500.0
MDSBG	174.2	55.8	261.7	0.0	8.3	500.0
MDSSA	100.0	26.7	336.6	0.0	36.7	500.0
CS	45.0	21.7	420.0	0.0	13.3	500.0
◎	103.0	32.9	335.8	8.3	20.0	500.0
SJ						
MDS-RDS	285.4	46.3	122.3	40.0	6.0	500.0
MDSBG	259.6	40.7	191.9	0.6	7.2	500.0
MDSSA	292.2	66.4	141.4	0.0	0.0	500.0
◎	279.1	51.1	151.9	13.5	4.4	500.0
EP						
MDS-RDS	366.1	38.3	92.3	3.3	0.0	500.0
MDSBG	360.4	27.3	102.3	10.0	0.0	500.0
MDSSA	326.4	23.3	139.0	0.0	11.3	500.0
MDSMV	230.0	82.7	173.0	14.3	0.0	500.0
◎	320.7	42.9	126.7	6.9	2.8	500.0

removed by the livestock at any time and in any quantity without implying abuse. For this reason, although the problems of the vertical stratification of these rangelands and how to estimate their equitable structural importance persist, it may be convenient to compare the sensitivity of density (an estimator of abundance) with simple basal area (an estimate of biomass) generally used in grasslands (Parker, 1954) to evaluate structural changes caused by the grazing pattern.

Differences in soil surface state between surveys

When estimating the state of the soil surface, it should be noted that, of the three rangeland sites found on the three ranches, those on EP had the highest mean values of bare soil (Table 4), implying that this ranch has the highest risk of erosion and desertification of the three ranches studied. However, the desirable species' density and biomass in EP were not the worst, possibly indicating a trend toward their recovery. It is worth mentioning that the soil surface of the rangeland sites on the LS ranch was outstanding, with the least amount of bare soil and the most vegetation of the three ranches studied. About the information on actual soil cover, the variables "bare soil", followed by the portion of soil covered by "vegetation" (equivalent to the structural attribute "basal area"), were those that were more closely related to condition, in accordance with its antecedents (Lara-Juárez *et al*., 2016; Bikila and Tessema, 2017; Aguirre-Rivera *et al*., 2020).

Multivariate ordering of the attributes evaluated in the surveys

Of the multivariate analysis applied to the variables vegetation and soil cover evaluated at each rangeland site, only the representative value of the first two ordering axes provided significant information for interpretation. Thus, the density and biomass of undesirable species, the density of less desirable species, the proportion of biomass and density of desirable species, and the proportion of bare soil are depicted on the far left of the first axis (Figure 2). In the upper part of axis two, the most significant variables for evaluating condition are ordered (density and biomass of desirable and undesirable species, density of less desirable species, and the proportion of bare soil), and in the lower part are the variables that were less sensitive or important for evaluating condition.

The results of multivariate ordering using DECORANA, which was originally designed to adjust ecological data from samples and species, were also appropriate for determining behavioral gradients of the set of vegetation and soil variables evaluated

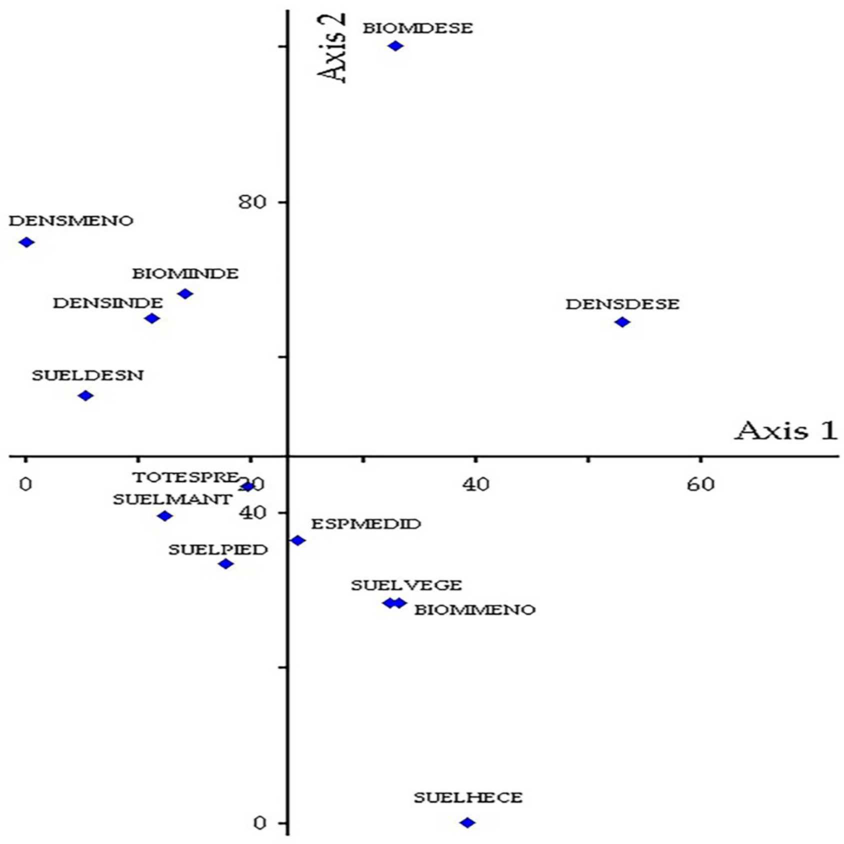

Figure 2. Bidimensional ordering of the variables evaluated in the rangeland sites of the studied ranches.

in this study and establishing the condition of different multi-branched rangeland sites subjected to different use patterns. These results coincided with those reported by Aguirre-Rivera *et al.* (2020) in semiarid rangelands under private management from 1993 to 2013, after parceling communal areas of the ejido El Castañón and Anexos, Catorce, San Luis Potosí. They also coincide with the pattern of gradients described by Reyes-Agüero *et al.* (2005) and Mora-López *et al.* (2011).

Classification of the evaluated rangeland sites

A multivariate classification of the rangeland sites was obtained based on the evaluated vegetation and soil surface variables (Figure 3). The 11 rangeland sites were classified into four groups comprising two to four sites each. The indicator variable, or causation, typical of the first dichotomy was the proportion of area covered by rocks, which separated groups 1 and 2 (six sites) from groups 3 and 4 (five sites). Thus, group 1 included only two rangeland sites, corresponding to the transition, or ecotone, between rosetophile (typical of hilly lithosols) and microphyll scrub with a rockier surface than the others, and the third site of this transition was placed in group 2, possibly because its condition was worse than the preceding two.

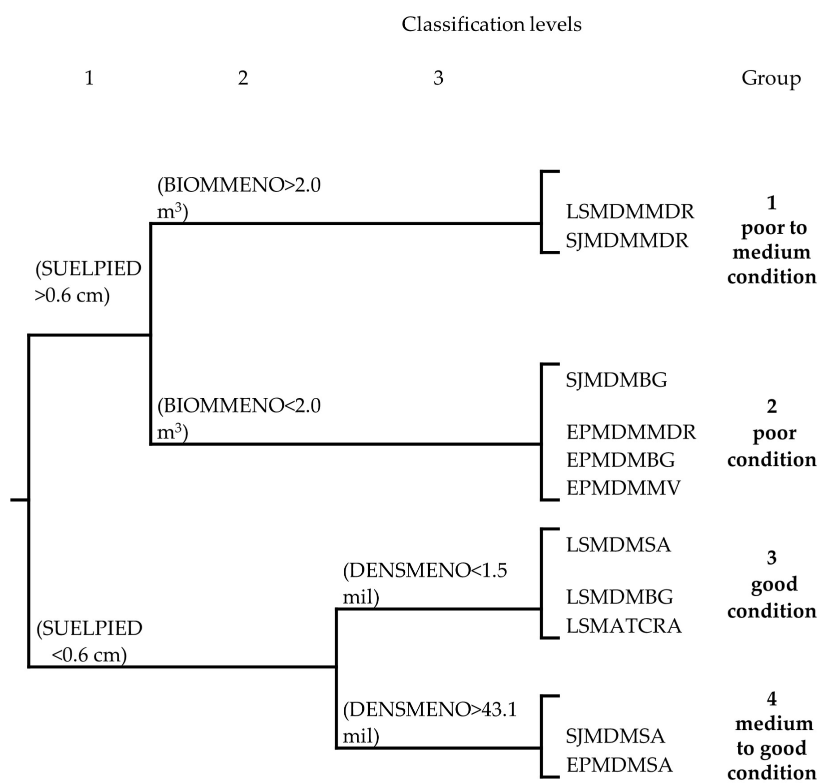

Figure 3. Classification of the 11 rangeland sites evaluated on three private ranches on the High Plateau in San Luis Potosí and Zacatecas, Mexico.

The separating indicator variable between groups 1 and 2 from classification level 2 was the biomass of less desirable species. The difference was due to the poorer condition of the sites in group 2. In classification level 3, groups 3 and 4 were defined due to the variable density of less desirable species, possibly the most sensitive vegetation variable when the condition begins to deteriorate. Thus, group 3 consisted of three LS sites, the ranch with the least deteriorated rangelands of the three studied, and group 4 was made up of the best conserved sites of the SJ and EP ranches, both with *Sporobolus airoides* as the dominant grass. In this way, multivariate classification of the evaluated sites confirmed the validity of their identification as such, but it also showed the effect of condition on generating affinity or distance between them.

To finalize, we anticipate that with the vegetation and soil cover variables evaluated in this study and the results found, we will have more useful indicators for designing and establishing a profitable and persistent production system of grazing animals. We also confirm that the methodology used (identification of sites with Landsat images, supervised classification, ecological quantification of vegetation and soil, and multivariate analysis) can be used to determine the condition of rangelands in any production unit located in similar ecological regions with the presence of multi-branched scrub.

CONCLUSIONS

The location and condition of multi-branched rangelands were studied using quantitative ecological methodology (the traditional method) supplemented with technology and analytical programming classification (the updated method), resulting in a satisfactory evaluation of the state of the rangelands on three privately owned cattle ranches on the High Plateau of the states of San Luis Potosí and Zacatecas, Mexico. The evaluation and classification of the 11 rangelands studied resulted in four condition groups, ranging from good to poor, with some transitions between the two extremes.

ACKNOWLEDGEMENTS

Our thanks to Ing. Jaime Valle Méndez, IAZ María de los Ángeles Vega Calzada and MVZ Herminio Gutiérrez Uribe, owners of LS, SJ, and EP respectively, for their enthusiastic willingness to support this study, to Estardo Camacho Rosales for his help in field work, and to the personnel of the herbarium IIZD of the UASLP, for identification of the collected specimens. We are grateful to the Consejo Nacional de Ciencia y Tecnología-CONACYT for the scholarship No. 230424, granted to L. O. Negrete S. for doctoral studies and to the editorial group and referees of *Agrociencia* for the care and constructive rigor in the treatment of the original version.

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