CLASSIFICATION OF PLANT COMMUNITIES IN SIERRA RICA, MANUEL BENAVIDES, CHIHUAHUA, MEXICO

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ABSTRACT

Sierra Rica is a mountain island located in the plains of the northeastern region of the Chihuahua Desert and has a diversity of vegetation patterns. To study this patterns the vegetation was characterized using GIS and cluster analysis, which identified five community types: pine forest (780 ha), oak forest (1640 ha), grassland (550 ha), desert scrub (866 ha), and rosetophyllous desert scrubland (628 ha). By the use of TWINSPAN software, four main vegetation groups containing 10 main plant associations were identified: (1) *Pinus-Quercus* forest, (2) grassland, (3) pine forest, (4) *Rhus-Juniperus,* (5) *Pinus-Quercus* and xeric species, (6) grassland-desert scrub, (7) desert microphyll scrub, (8) *Quercus-Aloysia-Bouteloua* association, (9) *Acacia constricta* scrubland, and (10) *Larrea tridentata* scrubland. The association among groups and species was significant ($P < 0.0001$). The subsequent analysis shows a high dependence among species inside the main groups and independence between groups.

RESUMEN

Sierra Rica es una montaña aislada ubicada en las planicies del noreste del Desierto Chihuahuense, presentando variación en la vegetación. La vegetación se clasificó por medio de SIG, el cual mostró cinco diferentes tipos de vegetación: bosque de pino (780 ha), bosque de encino (1640 ha), pastizal (550 ha), matorral desértico micrófilo (866 ha) y matorral desértico rosetófilo (628 ha). Para las asociaciones vegetales se utilizó un análisis de conglomerados mediante el programa TWINSPAN. Este análisis generó cuatro grupos principales, de los cuales se derivan 10 asociaciones vegetales: (1) bosque de *Pinus-Quercus,* (2) pastizal, (3) bosque de pino, (4) *Rhus-Juniperus,* (5) *Pinus-Quercus* y especies xéricas, (6) pastizal-matorral desértico, (7) matorral desértico micrófilo, (8) matorral de *Quercus-Aloysia-Bouteloua,* (9) *Acacia constricta* y (10) matorral de *Larrea tridentata.* La asociación entre cada uno de los grupos con las especies fue significativa ($P < 0.0001$). El análisis de correspondencias muestra una alta dependencia entre grupos con las especies e independencia entre grupos.

Key Words: Chihuahuan desert, plant associations, vegetation types, isolated mountain

INTRODUCTION

The Chihuahuan Desert Region (CDR) spans the Mexico-U.S. border, with the largest section located within the Mexican state of Chihuahua. Within the CDR there exist isolated mountains emerging from the desert. On the western side, some of these mountains are included in the Madrean Archipelago (MA), a group of 30–40 isolated mountain ranges located between the Rocky Mountains (north) and the Sierra Madre Occidental (south), and bridging the convergence of the Chihuahuan Desert (east) and the Sonoran Desert (west) (Poulos & Camp 2005; McCormack et al. 2009). The MA is commonly called the "Sky Islands" due to their separation from one another and to their unique combination of altitude, topography, and vegetation (Warshall 1994), traits shared by CDR mountains to the east of the MA area. The mountains of the CDR and MA are located between two major floristic zones, Neotropic and Holartic, making them a transition zone that is reflected in their floristic composition (Shmida 1985; Coblentz & Riitters 2004). The vegetation of mountains in the CDR,

in and out of the MA, is composed of temperate forest at high elevations surrounded by desert grasslands and shrublands below. They are hotspots for biodiversity and research, containing a wide diversity of species and ecosystems where diverse genotypes, vertical migration strategies, and patterns of speciation collide (Warshall 1994; Boyd 2002; Poulos et al. 2006; Bataineh et al. 2007). More than sixty percent of the plants in the pine and oak forests are probably endemic (Rzdowski, 1993) due to diverse evolutionary lineages caused by biogeographic isolation of Pleistocene relicts (Van Devender & Spaulding 1979). The region also contains big wildlife species such as black bear (*Ursus americanus*) and mountain lion (*Puma concolor*) (Hellgren 2004).

Several vegetation studies have been made in the CDR with plant communities classified by composition and structure in combination with climate and physiography (Miranda & Hernández 1963; Rzedowski 1978; INEGI 2013) as well as by qualitative characterization (Johnston 1977; Granados-Sánchez et al. 2011). Other studies have classified vegetation by characteristics such as rangeland coefficient and land use (COTECOCA 1978; INEGI 2013). A few studies have classified local areas within the CDR, such as the Trans-Pecos region in Texas (Powell 1980) and the Santa Elena Canyon Reserve (SEMARNAT 2013). After the vegetation is classified, each vegetation type can be characterized by plant associations, defined by the particular species composition and regular physiognomy caused by the dominant species (Granados & Vargas 2002). The isolated mountains of the northeastern CDR have been classified according to presence, frequency of species, and other characteristics. In the Guadalupe Mountains (Texas, U.S.A.) near Sierra Rica, the vegetation was classified based on aspect and elevation. The vegetation types are: coniferous forest, grassland, and shrubland, associated with *Quercus*, *Cercocarpus*, *Rhus*, *Dasylirion*, *Viguiera*, *Bouteloua*, and *Muhlenbergia* (Burgess & Northington 1977). A total of 13 different plant species were found associated with *Pinus ponderosa* in the Davis Mountains in Texas (Bataineh et al. 2007).Poulos and Camp (2005), with the use of Cluster analysis, identified six major associations between different forest groups in Big Bend National Park: *Juniperus deppeana-Pinus cembroides-Quercus grisea*, *Quercus gravesii-Cupressus arizonica*, *Juniperus flaccida-Pinus cembroides*, *Quercus emoryi-Quercus turbinella*, *Juniperus pinchotii-Quercus grisea*, and *Quercus grisea-Pinus cembroides-Juniperus deppeana*. Later, Poulos and Camp (2010) studied the vegetation in three mountain islands, the Chisos and Davis Mountains in Texas, and Maderas del Carmen in Coahuila Mexico. They report nine major plant communities: *Quercus grisea*, gallery forest, *Q. emoryi*, *Q. gravesii*, *Pinus cembroides*, *Quercus-Pinus-Juniperus*, *P. ponderosa*, *Cupressus-Abies*, and *Juniperus deppeana*. González (2001) identified the plant associations of the Santa Elena Canyon Flora and Fauna Protected Area, including several plant communities of Sierra Rica, based on species composition and elevation: *Muhlenbergia tenuifolia-Pinus cembroides-Quercus grisea*, *Bouteloua gracilis-Pinus cembroides-Quercus grisea-Muhlenbergia tenuifolia*, *Heteropogon contortus-Bouteloua curtipendula-Dasylirion leiophyllum*, and *Jatropha dioica-Acacia constricta-Larrea tridentata*.

The Isolated Mountain.—Sierra Rica is located in the northeastern area of the CDR, in the state of Chihuahua, Mexico, and is part of the Santa Elena Canyon Flora and Fauna Protected Area (SECFFPA). This area belongs to a binational complex of protected areas that include, in addition to SECFFPA, the Ocampo and Maderas del Carmen Flora and Fauna Protected Area in Coahuila Mexico, Chihuahua, and Rio Bravo del Norte Natural Monument, Big Bend National Park, Black Gap Wildlife Management Area, and Big Bend Ranch State Park in Texas. Notably, the Santa Elena Canyon and the Ocampo and Maderas del Carmen Flora and Fauna Protected Areas are composed primarily of private land devoted to cattle ranching. Together, these protected areas form a corridor for wildlife and genetic exchange that the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO) has designated as Priority Terrestrial Region 059 (SEMARNAT 2013). Within the SECFFPA, Sierra Rica is considered an important conservation and research site for ecological processes like carbon fixation and water filtration for the principal rivers of the area. It is also considered important for the conservation of biodiversity, including for several species of fauna and flora that are federally listed with some status in NOM-059-SEMARNAT, such as peregrine falcon (*Falco peregrinus*), golden eagle (*Aquila crysaethos*), and peyote (*Lophophora williamsii*), (SEMARNAT 2013). The vegetation in the area has a heterogeneous distribution, harboring a mixture of diverse plants communities such as pine forest, oak forest, grasslands, and scrubland.

The isolated mountains of eastern CDR in Mexico, have been little studied for vegetation composition. In Sierra Rica, vegetation has been studied through altitudinal degrees to determine dominant species and structure (Gonzalez and Sosa 2003). Because of the ecological importance and diversity of the place, more specific studies on vegetation are required. The present study includes types of vegetation and vegetal associations as well as the heterogeneity of these plant communities. The objective of this study is to increase the existing knowledge of the vegetation structure of Sierra Rica and complement the management program of the area.

MATERIALS AND METHODS

Study area. Sierra Rica covers an area of 4464 ha within the SECFFPA in the municipality of Manuel Benavides in the northeastern part of the state of Chihuahua (Fig. 1). The geographical location is 29°07'39.9"N, 104°10'46.62"W south and 29°1'36.86"N, 104°04'26.10"W north. Annual rainfall is 570 mm (SEMARNAT 2013) and average annual temperature is 21.2 °C (INEGI 2015). The topography varies from low hills to ravines and steep slopes of more than 30°. The Köppen climate classification, adapted by Garcia (1978), is BWhw, which corresponds to arid or desert type (SEMARNAT 2013). The area belongs to the Bravo-Conchos RH-24 Region and the Rio Bravo-Arroyo Ventanas sub-basin. The two main streams, both intermittent, are La Consolacion and Ventanas (INEGI 2013). The main soil types are rendizina and litosol, which are shallow and rest on extrusive igneous and sedimentary rocks (SEMARNAT 2012). The area is composed of multiple vegetation communities ranging from grasslands and shrublands at low elevation up to pine forests at the highest elevation (COTECOCA 1978; SEMARNAT 2013).

To generate a map with the vegetation types and distribution, we used a Lansat satellite image OLI8 from the U.S. Geological Survey (2013). The date of the selected image was July 23, 2013, when the area was free of clouds and the colors of vegetation types were distinctive. With the software IDRISI Selva and ArcGis 10.1, the image was prepared to elaborate the digital elevation model and classification of the principal vegetation types with the non-supervised technique.

Sample size was determined using species-area curve, which provides a minimum sampling area, given the largest likely number of species (Mostacedo & Frederiksen 2000). The species-distance curve shows stability of occurrence of species at a distance of 3180 m corresponds to 129 sites, with 120 identified species (Fig. 5). The species-area curve shows 129 sampling points like the minimum size. These points were established along an altitude gradient and separated by at least 100m (Table 1). At every sampling point, the canopy cover of each species was recorded using a line intercept method with 30 m transected in a random direction (Herrick et al. 2009). Thirty-six perennial species and one annual (Table 2) (with occurrence of 0.5% or more following the criteria of Gonzalez & Sosa 2003) were selected to classify the main plant communities of the area using TWINSPAN software, ver. 2.3 (Hill & Ŝmilauer 2005). Vegetation types and plant associations were classified following Miranda and Hernandez (1963) and Rzedowski (1978) to describe the resulting dendogram from TWINSPAN. To test the effectiveness of the classification dendrogram, a chi-square (*X2*) test was performed (SAS Institute Inc. 9.1.3. 2006 software), looking for possible associations of the vegetation group with existing plant species, as well as differences in species compositions between groups.

RESULTS

The non-supervised classification of the two satellite images resulted in a map with five vegetation groups: oak forest, pine forest, desert scrub, rosetophyllous desert scrub, and grassland (Fig. 2). The oak forest comprised 1640 ha (36.73%) of the area, distributed in north-facing canyons and eastern slopes. Pine forest comprised 780 ha (17.47%), located mainly on steep canyons and slopes with western exposure. Grasslands comprised 550 ha (12.32%), distributed in the highest areas adjacent to pine forest and in low-lying areas with southern exposure. Desert scrub made up 866 ha (19.39%) surrounding the lower part of the mountain. The rosetophyllous desert scrubland, 628 ha (14.06%) was located only in a small southwestern portion of the study area.

The dendrogram generated from transect data using TWINSPAN (Fig. 3) showed four main vegetation groups: Group I, *Pinus-Quercus* forest and grassland with two different associations; Group II, conifer forest

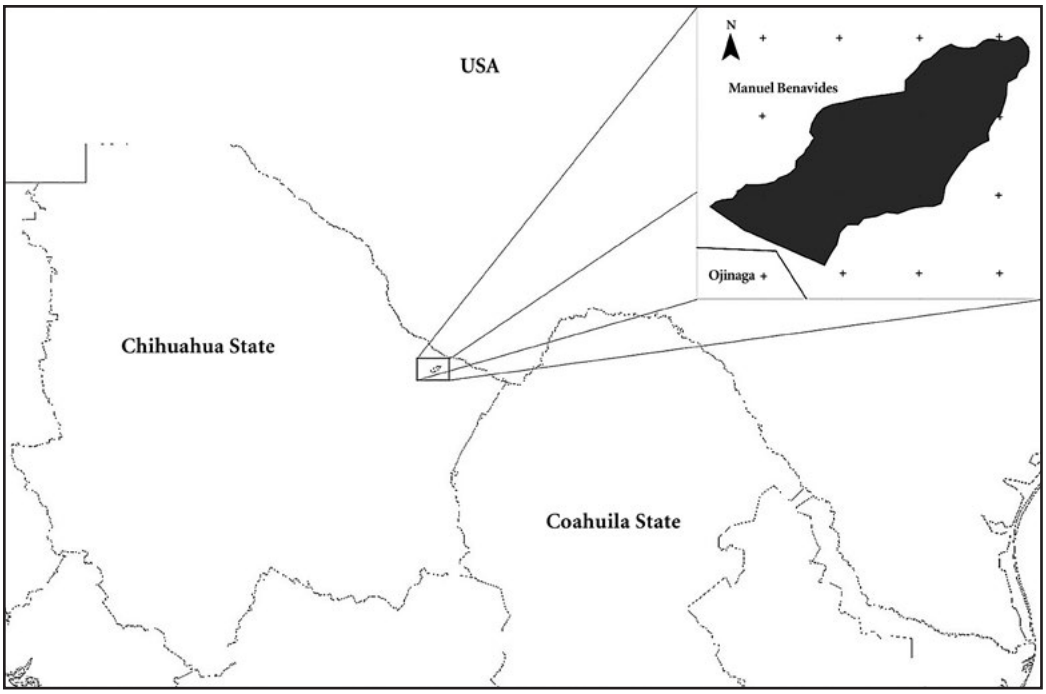

Fig. 1. Location of Sierra Rica, Manuel Benavides in Chihuahua, México.

Table 1. Number of sites per elevation belt within the study area of Sierra Rica, Manuel Benavides in Chihuahua, Mexico.

Elevation (m)	Sites
1400–599	14
1600–799	26
1800–999	58
2000–199	23
2200–409	8

with three different associations; Group III, desert scrub with three different associations; and Group IV, with only one association: *Acacia-Larrea* scrubland.

Group I includes 22 sites, with pine-oak forest and grassland at an altitude of 1750–2300 m. The dominant species are *Pinus remota, Quercus grisea,* and *Muhlenbergia* spp. Two associations are present. SUB IA includes nine sites dominated by a *Pinus-Quercus* association. The main species are the trees *Pinus remota, Quercus grisea,* and *Q. oblongifolia* associated with the grasses *Muhlenbergia* spp., *Aristida divaricata, Juniperus deppeana, J. monosperma,* and *Arbutus xalapensis*. SUB IB includes 13 sites across an elevation range of 1600–2200 m. This subgroup corresponds to grassland associated with shrubs and trees. The dominant species are *Muhlenbergia tenuifolia, M. montana, Bouteloua curtipendula, B. gracilis, Aristida adscencionis,* and *Piptochaetium fimbriatum* associated with *Pinus remota, Quercus grisea, Q. oblonguifolia, Juniperus deppeana, J. monosperma, Rhus virens, R. trilobata*, and *Mahonia trifoliolata.*

Group II comprises 44 sites distributed across an elevation range of 1700–2409 m, is dominated by conifer forest, and contains three subgroups. SUB IIA includes 13 sites in which the dominant species is *Pinus remota* associated with *Quercus vaseyana, Q. arizonica, Q. pungens, Juniperus deppeana J. monosperma, Rhus*

Table 2. Species with 0.5% or greater occurrence in the sampling sites (* = species with protection status).

Species	Life Form	Occurrence (%)
Acacia constricta A. Gray	Shrub	4.4
Agave havardiana Trel.	Shrub	1.3
Aloysia gratissima (Gillies & Hook.) Tronc.	Shrub	1.3
Aloysia wrightii A. Heller	Shrub	3.8
Arbutus xalapensis Kunth	Tree	0.6
Aristida adscencionis L.	Graminoid	1.8
Aristida divaricata Humb. & Bonpl. ex Willd.	Graminoid	0.8
Bouteloua curtipendula (Michx.) Torr.	Graminoid	6.2
Bouteloua gracilis (Kunth) Lag. ex Griffiths	Graminoid	2.4
Cheilanthes villosa Davenp. ex Maxon	Herbs	1.3
Dasylirion leiophyllum Engelm. ex Trel.	Shrub	2.0
Fouquieria splendens Engelm.	Shrub	1.4
Heteropogon contortus (L.) P. Beauv. ex Roem. & Schult.	Graminoid	4.2
Juniperus deppeana Steud.	Tree	1.8
Juniperus monosperma (Engelm.) Sarg.	Tree	3.7
Larrea tridentata (Sessé & Moc. ex DC.) Coville	Shrub	0.7
Leptochloa dubia (Kunth) Nees	Graminoid	0.7
Mohonia trifoliolata (Moric.) Fedde	Shrub	0.8
Mimosa aculeaticarpa Ortega	Shrub	4.0
Muhlenbergia spp.	Graminoid	0.8
Muhlenbergia montana (Nutt.) Hitchc.	Graminoid	1.2
Muhlenbergia tenuifolia (Kunth) Kunth	Graminoid	3.5
Nolina texana S. Watson	Shrub	1.1
Parthenium incanum Kunth	Shrub	0.7
Piptochaetium fimbriatum (Humb., Bonpl., & Kunth) Hitchc.	Graminoid	0.8
**Pinus remota* (Little) D.K. Bailey & Hawksw.	Tree	15.7
Prosopis glandulosa Torr.	Shrub	1.0
Quercus arizonica Sarg.	Tree	1.5
Quercus grisea Liebm.	Tree	5.3
Quercus oblongifolia Torr.	Tree	4.5
Quercus pungens Liebm.	Tree	2.0
Quercus vaseyana Buckley	Tree	1.5
Rhus microphylla Engelm.	Shrub	0.7
Rhus trilobata Nutt.	Shrub	1.2
Rhus virens Lindh. ex A. Gray	Shrub	3.7
Viguiera stenoloba S.F. Blake	Shrub	5.4
Viguiera cordifolia A. Gray	Shrub	1.0

virens, R. trilobata, Agave havardiana, Nolina texana, Mahonia trifoliolata, Aristida adscencionis, and *Piptochaetium fimbriatum*. SUB IIB comprises seven sites with an elevation range of 1800–2000 m. In this subgroup, the pine forest is associated with *Rhus virens, R. trilobata, R. microphylla, Juniperus monosperma, J. deppeana, Quercus vaseyana* and *Q. oblongifolia* with an understory of *Mahonia trifoliolata* and *Bouteloua curtipendula.* SUB IIC, ranging from 1600–2000 m, presents a heterogeneity of species on twenty-four sites where *Pinus-Quercus* forest with shrubby species is the dominant vegetation. The main species are *Pinus remota, Quercus oblongifolia, Q. pungens, Juniperus monosperma, Mimosa aculeaticarpa* var. *biuncifera, Acacia constricta, Fouquieria splendens, Aloysia wrightii, A. gratissima, Viguiera cordifolia,* and *Bouteloua curtipendula*.

Group III includes 50 sites of desert scrub occupying low-lying areas of the mountains at 1500–1900 m and is divided among three subgroups. *Bouteloua curtipendula, Heteropogon contortus, Aristida divaricata, Aloysia gratissima, Mimosa aculeaticarpa* var. *biuncifera, Acacia constricta*, and *Viguiera stenoloba* are the characteristic species. The 19 sites of SUB IIIA are composed of tussock grassland and desert scrubland located at 1600–1900 m. The dominant species are *Aloysia gratissima, Acacia constricta, Fouquieria splendens, Dasylirion leiophyllum, Quercus pungens, Agave havardiana, Heteropogon contortus, Bouteloua curtipendula,* and *Viguiera stenoloba*. SUB IIIB includes 22 sites dominated by desert scrubland at 1450–1700 m. The main species of this

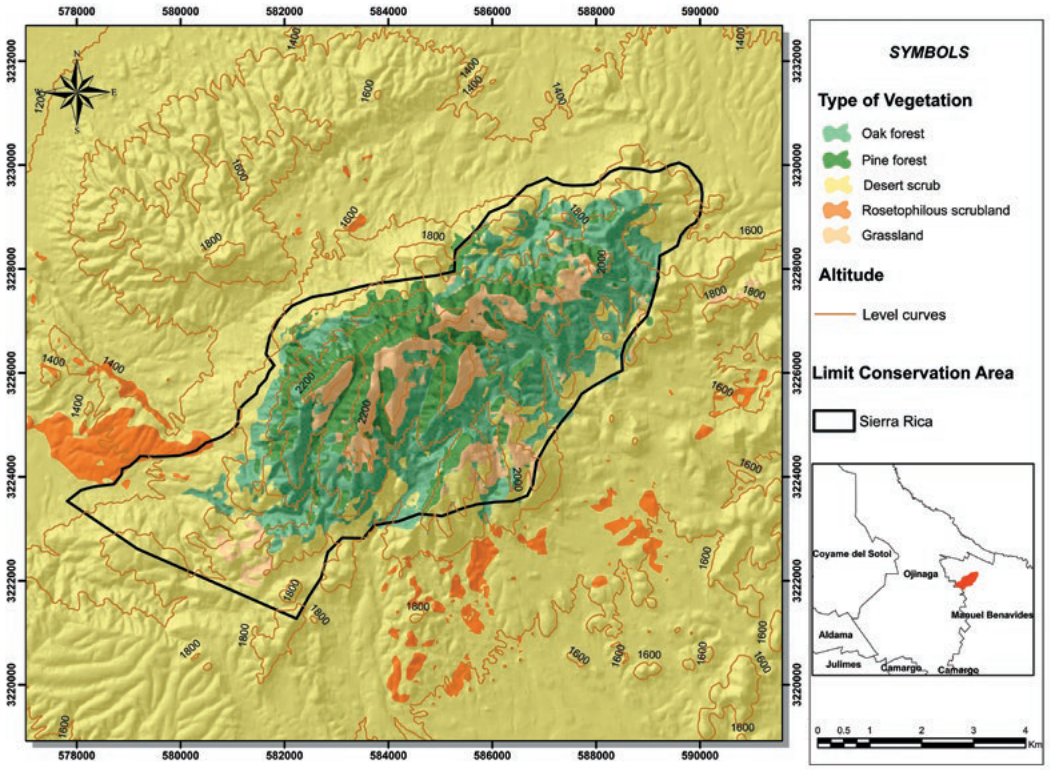

Fig. 2. Non-supervised classification of vegetation types on Sierra Rica.

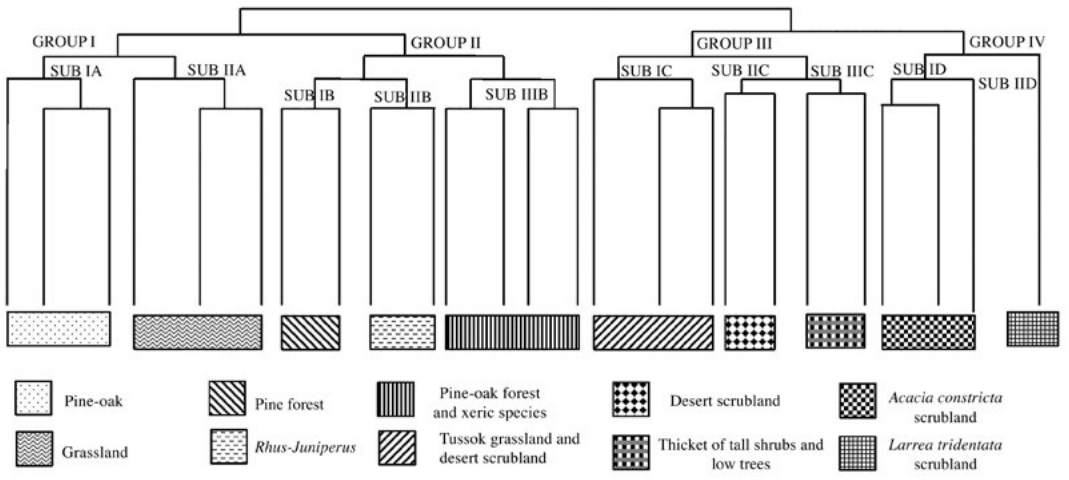

Fig. 3. Dendrogram generated by TWINSPAN showing the classification of four major groups of plant associations on Sierra Rica.

association are: *Aloysia wrightii, Rhus virens, Viguiera stenoloba, Acacia constricta, Parthenium incanum, Fouquieria splendens, Heteropogon contortus, Bouteloua curtipendula,* and *Agave havardiana*. SUB IIIC includes 9 sites at 1600–1800 m of thickets of tall shrubs and low trees. The main species are *Quercus pungens, Aloysia wrightii, Bouteloua curtipendula, B. gracilis, Pinus remota,* and *Viguiera stenoloba*.

Group IV corresponds to desert scrub and is composed of 13 sites in two associations at 1400–1600 m, in the lower parts of the mountains and valleys that are bordered by desert vegetation. SUB IVA includes 11 sites of *Acacia constricta* scrubland co-dominated by *Viguiera stenoloba, Mimosa aculeaticarpa var. biuncifera, Prosopis glandulosa, Aloysia wrightii, Fouquieria splendens, Juniperus monosperma,* and *Larrea tridentata*. SUB IVB includes two sites in the southern part of the mountains at an altitude of 1450 m. *Larrea tridentata, Acacia constricta, Aloysia gratissima, Parthenium incanum,* and *Prosopis glandulosa* are the dominant species.

Significance Test for the Vegetation Groups.—Results of the cluster analysis were statistically significant ($X^2 = 1.09847$, $P < .0001$). The association and independence among species and groups based on the correspondence analysis were similar to the results of the cluster analysis. A simple correspondence graph was constructed to show the asociation between the four groups of vegetation with the most common species (Fig. 4): pine-oak forest and grassland (G1) are associated with the species *Quercus oblongifolia* (L26), *Arbutus xalapensis* (L33), *Piptochaetium fimbriatum* (L22), *Muhlenbergia tenuifolia* (L37), *M. montana* (L19), *Pinus remota* (L23), *Aristida divaricata* (L36), and *Juniperus deppeana* (L13). Coniferous forest (G2) has its main association with *Quercus grisea* (L34), *Q. vaseyana* (L35), *Q. arizonica* (L25), *Muhlenbergia* spp. (L18), *Rhus trilobata* (L29), *R. virens* (L30), *Juniperus monosperma* (L14), and *Leptochloa dubia* (L16). *Mahonia trifoliolata* (L6), *Bouteloua gracilis* (L8), *B. curtipendula* (L7), *Vigueria cordifolia* (L32), *Mimosa aculeaticarpa* (L17), *Rhus microphylla* (L28), and *Nolina texana* (L20) were found in groups G2 and G3, indicating the close similarity between these groups. Desert scrub (G3) is associated with *Aristida adscencionis* (L5), *Dasylirion leiophyllum* (L10), *Fouquieria splendens* (L11), *Heteropogon contortus* (L12), *Parthenium incanum* (L21), *Leptochloa dubia* (L16), *Aloysia gratissima* (L3), and *Vigueria stenoloba* (L31). Finally, the *Acacia-Larrea* desert scrub (G4) also includes *Acacia constricta* (L1), *Prosopis glandulosa* (L24), and *Larrea tridentata* (L15).

DISCUSSION

This research demonstrates the heterogeneity of vegetation communities associated with mountains in northeast CDR. The non-supervised classification indicates the current distribution of five types of vegetation on Sierra Rica where higher elevation pine forest and grassland is surrounded by a ring of lower elevation oak forest below which is a plain of desert scrub. Pine forest is located primarily in canyons and hills with northwestern exposure and is dominated by the relict specie *Pinus remota*. This species can also be found at lower sites within desert scrub, but only in transitions zones or on northwestern exposures. *Pinus remota* has been found to have a wide distribution since the Pleistocene era (Lanner & Van Devender 1981). Its widespread presence here testifies to the varied microclimates caused by the topography of the isolated mountain (Poulos & Camp 2010).

According to COTECOCA (1973), grasslands in this region are typically dominated by bunch grasses with trees and shrubs at upper elevations. The TWINSPAN classification identified one unique site, at lower elevations in the southeastern area with tussock grassland and a few species of trees and shrubs.

The non-supervised classification identified that two species *Quercus pungens* and *Q. vaseyana* surrounded the lower valley of the area. These species are mixed with desert scrub. Some authors describe these species as part of the chaparral (Rzedowski 2006). In our case, the non-supervised classification placed all *Quercus* spp. in one vegetation type. The rosetophilous scrubland coincides with the distribution made by INEGI 2011. It is a small area in the southwestern section of the study area typified by species of scrub and succulents from the families Cactaceae and Agavaceae (Rzedowski 2006). Between the elevations of 1400 and 2000 m, multiple interactions of this vegetation type can be found, such as *Hetchia texensis* with *Pinus remota* at lower elevations and *Agave havardiana*, *Yucca carnerosana,* and *Yucca faxoniana* with *Quercus* spp. and *P. remota* at higher elevations. *Yucca* spp. are only rarely dominant, most often in rolling hills with northeastern

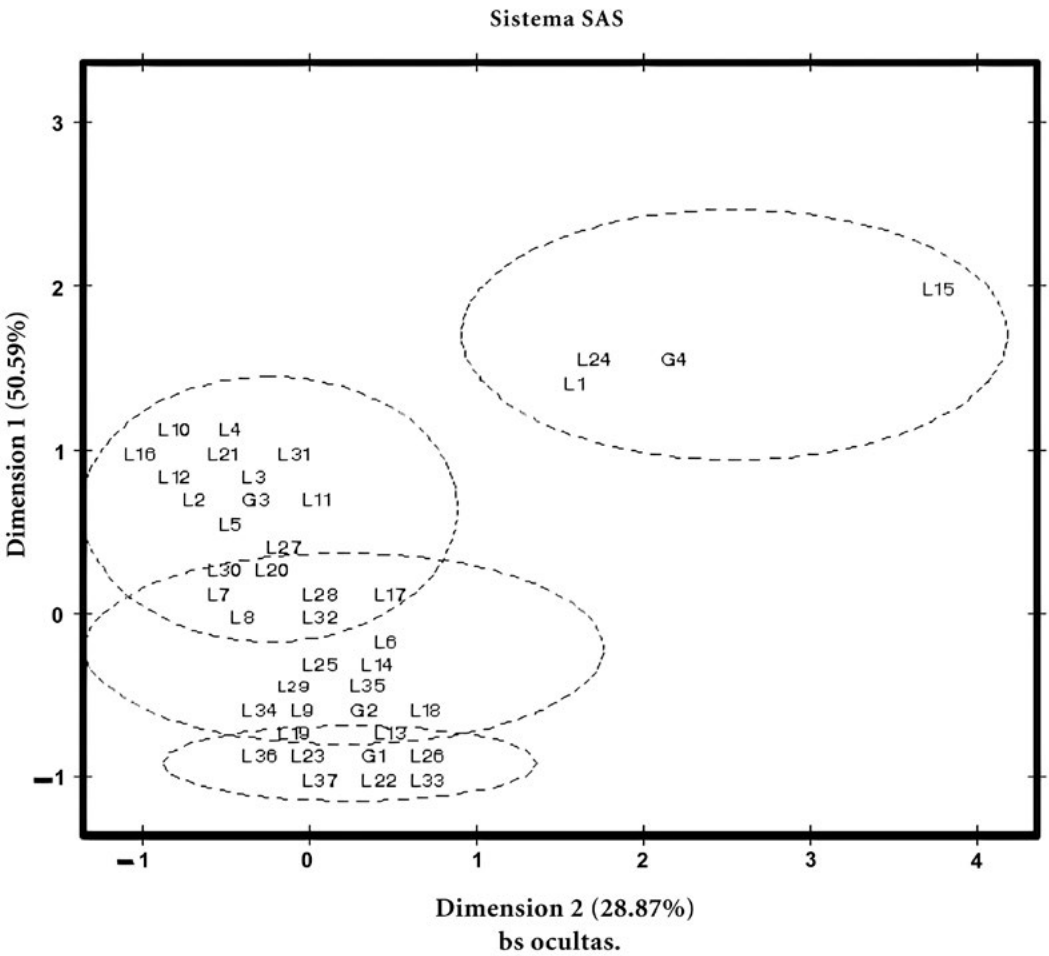

Fig. 4. Simple correspondence analysis showing the major groups of vegetation (G1–G4) associated with the species with major occurrences on Sierra Rica (L1–L37). See results for taxa associated with the numbered occurrences.

exposure, though there are small areas resembling yucca forest (izotal) (Rzedowski 2006). *Yucca* spp.-dominated sites were not identified in the non-supervised classification, likely due to their small area and lack of unique spectral signature.

Another type of vegetation that is present in Sierra Rica, but not included in this study, is gallery forest. This forest is typically composed of *Cupressus arizonica*, *Fraxinus velutina*, *Prunus serotina*, and *Juglans microcarpa*, among other trees. It typically occupies shady, low-elevation valley bottoms such as the Madera canyon. Similar gallery forests are also found at the nearby isolated mountain Maderas del Carmen in Coahuila (Poulos & Camp 2010).

Isolated mountains in North America are typified by bands of vegetation at lower elevations. Sierra Rica presents similar vegetation associations as other isolated mountain in the CDR. The species *Acacia constricta*, *Bouteloua curtipendula*, *Heteropogon contortus*, *Mimosa aculeaticarpa* var. *biuncifera*, *Pinus remota*, *Quercus grisea*, *Q. oblogifolia,* and *Vigueria stenoloba* all have occurrence values greater than 0.4%. Like at Sierra Rica, *Pinus-Quercus* associations are also present at high elevations in the Maderas del Carmen, Davis, Guadalupe, and Chisos Mountains (Poulos & Camp 2010; Muldavin et al 2014; Bunting 1978).The difference between

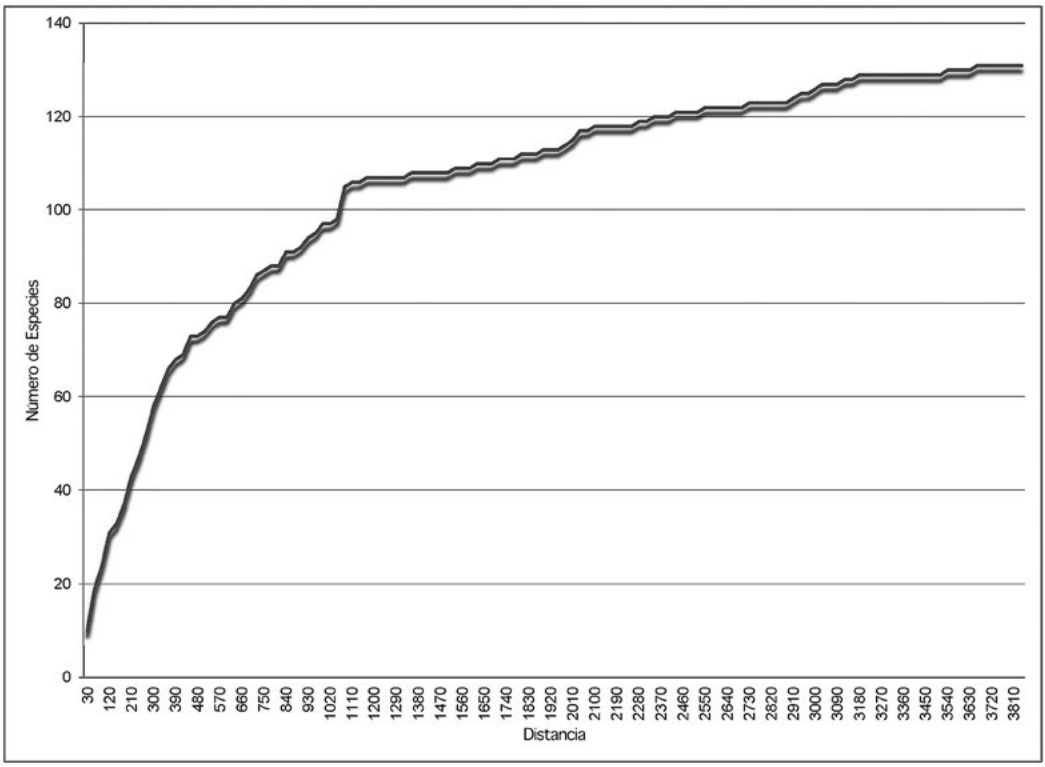

Fig. 5. Species-Distance Curve, to determine minimum sampling area.

these areas is the composition of species. On Sierra Rica, *Pinus remota*, *Quercus grisea,* and *Q. oblogifolia* are dominant while the other areas have more temperate species like *Pinus cembroides*, *Pseudotsuga* spp., *Abies* spp , and *Picea* (SEMARNAT 2013).This can be partly attributed to differences in elevation, but in the Davis Mountains (Powell 1980) and Maderas del Carmen (Muldavin et al. 2014) *Pinus remota* is dominant at lower elevations, similar to that of scrub-land.

The high elevation grasslands are dominated by *Muhlenbergia*, *Bouteloua,* and *Piptochaetium*. These genera are common throughout CDR grasslands, but in Sierra Rica the species *Aristida adscensionis* is co-dominant in this association. Its detection in this study was made possible by the timing of our sampling which occurred during the rainy season when annuals are more visible. Despite being an annual species, it was included in our analysis because of its abundance.

The diversity of plant communities at Sierra Rica results from its physiography and diverse microclimates (Gonzalez & Cerecedo 2003). But the over-all vegetation in the area has not been well studied. Several regional studies (LeSueur 1945; Powell 1980; Jiménez-Guzmán & Zúñiga-Ramos 1991; Van Devender & Reina 2005; Poulos et al. 2006; Sosa et al. 2006; Bataineh et al. 2007; Poulos & Camp 2010; Granados et al. 2011) agree that altitude is a determining factor of vegetation distribution. This is also true for Sierra Rica, where different plant communities and vegetation types were observed along the elevational gradient. Except at the highest peaks, xeric species were frequently intermixed with temperate species across elevations.

Sierra Rica is an isolated mountain that presents vegetation of forest, scrubland, and grassland surrounded by valleys with vegetation of desert scrub which prevents genetic exchange with populations that inhabit other mountain islands with similar vegetation. This characteristic makes it unique in terms of composition of species and types of vegetation. At the same time, it is an area for the protection of larger fauna like

migratory black bear (*Ursus americanus*) and endemics such as white-tailed deer (*Odocoileus virginianus*), cougar (*Puma concolor*), and collared peccary (*Tayassu tajacu*). We believe the present study provides a basis for ongoing investigations of the Sierra Rica area. Regular vegetation monitoring is recommended and needed to track and mitigate the change in land use and the effects of climate change.

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REFERENCES

Batayneh, M.M., B.P. Oswald, A.L. Batayneh, K.W. Farrish, & D.W. Coble. 2007. Plant communities associated with *Pinus ponderosa* forests in the Sky Islands of Davis Mountains, Texas. J. Torrey Bot. Soc. 134:468–478.

Boyd, A. 2002. Morphological analysis of Sky Islands populations of *Macromeria viridiflora* (Boraginaceae). Syst. Bot. 27:116–126.

Bunting, C.S. 1978. The vegetation of the Guadalupe Mountains. Dissertation in Agriculture. Texas Tech University, Lubbock, U.S.A.

Burgess, L.T. & D.K. Northington. 1977. Desert vegetation in the Guadalupe Mountains region. In: R.H. Wauer & D.H. Riskind, eds. Transactions of the symposium on the biological resources of the Chihuahuan Desert Region United States and Mexico. Sul Ross State University, Texas, U.S.A. Pp. 229–242.

Coblentz, D. & K.H. Riitters. 2004. Topographic controls on the regional-scale biodiversity of the south-western USA. J. Biogeogr. 31:1125–1138.

COTECOCA. 1978. Estudio para el estado de Chihuahua. Secretaría de Agricultura y Recursos Hidráulicos. Comisión Técnico Consultiva para la Determinación Regional de los Coeficientes de Agostadero. México, D.F.

González, P.A. 2001. Caracterización ecológica de la vegetación en las áreas de flora y fauna cañón de Santa Elena y Big Bend National Park. Ph.D. Disertación. Universidad Autónoma de Chihuahua, Facultad de Zootecnia y Ecología, Chihuahua, México.

González, P.A. & M.S. Cerecedo. 2003. Análisis de la vegetación del área de protección de flora y fauna cañón de Santa Elena (Desierto Chihuahuense) utilizando modelos digitales de elevación. Ecosistemas 2:1–6.

Granados-Sánchez, D., A. Sánchez-González, R.L.G. Victorino, & A. Borja de la Rosa. 2011. Ecología de la vegetación del Desierto Chihuahuense. Revista Chapingo, Ser. Ci. Forest. 17:111–130.

Granados, S.D. & R.T. Vargas. 2002. Comunidades vegetales. 1a reimpresión. Universidad Autónoma Chapingo, México. Pp. 235.

Herrick, J.E., J.W. Van Zee, K.M. Havstad, L.M. Burkett, & W.G. Whitford. 2009. Monitoring manual for grassland, shrubland and savana ecosystems. United States Department of Agriculture-Agricultural Research Service Jornada Experimental Range, Las Cruces, New Mexico, U.S.A.

Hill, M.O. & P. Ŝmilauer. 2005. TWINSPAN for Windows, versión 2.3. Guía de usuario. Centro de Ecología e Hidrología, Universidad de South Bohemia, Republica Checa.

INEGI. 2013. Anuario estadístico y geográfico por entidad federativa. Instituto Nacional de Estadística y Geografía, México. Pp. 744.

Jiménez-Guzmán, A. & M. Zuñiga-Ramos A. 1991. Caracterización biológica de Sierra Maderas del Carmen, Coahuila, México. Anales Inst. Biol. Univ. Nac. Auton. Mexico, Ser. Zool. 62:378–382.

Johnston, M.C. 1977. Brief resume of botanical, including vegetational features of the Chihuahuan desert region with special emphasis on their uniqueness. In: R.H. Wauer & D.H. Riskind, eds. Transactions of the symposium on the biological resources of the Chihuahuan desert region United States and Mexico, Sul Ross State University, Texas, U.S.A. Pp. 33–359.

Lanner, M.R. & T.R. van Devender. 1981. Late Pleistocene piñon pines in the Chihuahuan Desert. Quaternary Res. 15:278–290.

Lesueur, H. 1945. The ecology of the vegetation of Chihuahua, Mexico, north of the parallel twenty-eight. Univ. Texas Publ. 4521.

McCormack, J.E., H. Huang, & L.L. Knowles. 2009. Sky Islands. In: R.G. Gillespie & D.A. Clague, eds. Encyclopedia of islands. University of California, U.S.A. Pp. 839–843.

Miranda, F. & X. Hernández. 1963. Los tipos de vegetación de México y su clasificación. Bol. Soc. Bot. Mex. 28:29–179.

Mostacedo, B. & T.S. Fredericksen. 2000. Manual de métodos básicos de muestreo y análisis en ecología vegetal. Santa Cruz, Bolivia.

Muldavin, E.H., H. Glenn, N. Paul, & W. Sarah. 2014. A vegetation classification of the Sierra del Carmen, U. S. A. and México. In: C.A. Hoyt & J. Karges, eds. Proceedings of the Sixth Symposium on the Natural Resources of the Chihuahuan Desert Region. October 14–17. Chihuahuan Desert Research Institute, Fort Davis, Texas, U.S.A. Pp. 117–150. http://cdri.org/publications/proceedings-of-the-symposium-on-the-naturalresources-of-the-chihuahuan-desert-region/

Poulos, H.M. & A.E. Camp. 2005. Vegetation-environment relations of the Chisos Mountains, Big Bend National Park, Texas. USDA Forest Service Proc. RMRS 36:539–544.

Poulos, H.M. & A.E. Camp. 2010. Topographic influences on vegetation mosaics and tree diversity in the Chihuahuan Desert borderlands. Ecology 91:1140–1151.

Poulos, H.M., A.H Taylor, & M.R. Beaty 2006. Environmental controls on dominance and diversity of woody plant species in a Madrean, Sky Island ecosystem, Arizona, U.S.A. Pl. Ecol. 193:15–30.

Powell, A.M. 1980. Vegetation of Trans-Pecos Texas. New Mexico Geological Society Guidebook. New Mexico Geological Society, Socorro, New Mexico, U.S.A. Pp. 299–302.

Rzedowski, J. 1978. Vegetación de México. Ed. Limusa. México.

SAS Institute, Inc. 2006. SAS 9. 1. 3. User's guide. SAS Institute, Cary, North Carolina, U.S.A.

SEMARNAT. 2012. Atlas de medio físico biótico y ambiental del estado de Chihuahua. México.

SEMARNAT. 2013. Programa de manejo área de protección de flora y fauna cañón de Santa Elena. 1ra ed. Comisión Nacional de Áreas Naturales Protegidas, México.

Shmida, A. 1985. Biogeography of the desert floras of the world. Hot deserts and arid shrublands, Elsevier, Amsterdam, The Netherlands. 12:23–77.

Sosa, M., J.M. Galarza, T. Lebgue, R. Soto, & S. Puga. 2006. Clasificación de las comunidades vegetales en la región árida del estado de Chihuahua, México. Ecología Aplicada 5:53–59.

USGS. 2013. Satellite Imagery. Available at earthexplorer.usgs.gov. United States Geological Survey, U.S.A. Accessed 26 July 2013.

van Devender, T.R. & G.A.L. Reina. 2005. Floristic comparison of an Arizona Sky Island and the Sierra Madre Occidental in eastern Sonora: The Huachuca Mountains and the Yécora area. United States Dept. Agric. Forest Service Proc. RMRS-P 36:154–157.