Vegetation on geomorphic surfaces in the Monserrat Island in the Gulf of California

Article *in* Ecosistemas y Recursos Agropecuarios · August 2020

DOI: 10.19136/era.a7n2.2334

ECOSISTEMAS Y RECURSOS AGROPECUARIOS

Vegetation on geomorphic surfaces in the Monserrat Island in the Gulf of California

Vegetación en geoformas de la isla Monserrat en el Golfo de California

Victor Ortiz-Ávila[1],
Gustavo A. Arnaud-Franco[2],
Eduardo Estrada-Castillón[3],
Eloy A. Cavazos-Lozano[4],
Guillermo Romero[5],
Miguel Mellado[1*]

[1]Autonomous Agrarian University Antonio Narro, Department of Animal Nutrition, Saltillo, Mexico.
[2]Northwest Biological Research Center, La Paz, Mexico.
[3]Autonomous University of Nuevo Leon, Forestry Department, Linares, Mexico.
[4]Autonomous Agrarian University Antonio Narro, Department of Renewable Natural Resources, Saltillo, Mexico.
[5]Universidad Autonomous Univesity of Baja California, Faculty of Sciences, Ensenada, Mexico.

[*]Corresponding author:
mmellbosq@yahoo.com

Scientific article
Received: june 07, 2019
Accepted: june 05, 2020

How to cite: Ortiz-Ávila V, Arnaud-Franco GA, Estrada-Castillón E, Cavazos-Lozano EA, Romero G, Mellado M (2020) Vegetation on geomorphic surfaces in the Monserrat Island in the Gulf of California. Ecosistemas y Recursos Agropecuarios 7(2): e2334. DOI: 10.19136/era.a7n2.2334

ABSTRACT. Knowledge about vegetation patterns along topographic gradients is crucial for conservation and management of arid islands. The objective of this study was to identify environmental, soil, and topography variables affecting plant distribution in Monserrat Island. A floristic and environmental survey was undertaken on this island (25° 41' 00" N, 111° 03' 00" W; 19.9 km^2) in the Gulf of California, Mexico. Seven geoform zones were distinguished. The vegetation is predominantly a sarcocaule xerophilous scrub which develops mainly in ravines and bottoms of streams. One hundred fourteen species were recorded, of which 33 plants (28.9%) are endemic belonging to 92 genera and 38 families of vascular plants. The most abundant families were: Asteraceae, Euphorbiaceae, Fabaceae, Poaceae, and Cactaceae. The *Bursera* trees are more abundant in areas with little steep slopes (less than 25°). On areas with steep slopes (greater than 45°), the development of vegetation is scarce. Northern exposure slopes had denser vegetation, with higher canopy cover values. Slope was far more reliably measure for describing vegetation distribution than altitude, although, the latter variable influences *Olneya tesota*. *Euphorbia magdalenae* was strongly associated with slope, and both *Jouvea pilosa* and *Marina parryi* was influenced by soil characteristics. *Jatropha cuneata* was found in almost all geoforms. It was concluded that Monserrat Island possesses a distinctive mix of xeric species making this island unique due to the high presence of endemic plants.
Key words: Baja California, endemic plants, geomorphic areas, island biogeography, sarcocaule xerophilous scrub.

RESUMEN. El conocimiento de los patrones de la vegetación en gradientes topográficos es crucial para la conservación y el manejo de islas en ecosistemas áridos. El objetivo de este estudio fue identificar variables ambientales, de suelo y topográficas que afectan la distribución de las plantas en la Isla Monserrat. Se realizó un estudio florístico y ambiental en esta isla (25° 41' 00" N, 111° 03' 00" O; 19.9 km^2) en el Golfo de California, México. Se distinguieron siete geoformas. La vegetación es predominantemente un matorral sarcocaule xerófilo que se desarrolla principalmente en barrancos y fondo de arroyos. Se registraron 114 especies de plantas, de las cuales 33 (28.9%) son endémicas y pertenecen a 92 géneros y 38 familias de plantas vasculares. Las familias más abundantes fueron: Asteraceae, Euphorbiaceae, Fabaceae, Poaceae y Cactaceae. Los árboles de *Bursera* son más abundantes en áreas con pequeñas pendientes pronunciadas (menos de 25°). En áreas con pendientes pronunciadas (más de 45°), el desarrollo de la vegetación es escaso. Las pendientes de exposición norte tienen una vegetación más densa, con valores más altos de cobertura del dosel. La pendiente fue mucho más confiable para describir la distribución de la vegetación que la altitud, aunque esta última variable influye en *Olneya tesota*. *Euphorbia magdalenae* está fuertemente asociada con la pendiente, y tanto *Jouvea pilosa* como *Marina parryi* están influenciadas por las características del suelo. *Jatropha cuneata* se encontró en casi todas las geoformas. Se concluyó que la Isla Monserrat posee una mezcla distintiva de especies xéricas que hacen que esta isla sea única debido a la alta presencia de plantas endémicas.
Palabras clave: Baja California, biogeografía de islas, geoformas, matorral sarcocaule, plantas endémicas.

E. ISSN: 2007-901X

INTRODUCTION

Insular ecosystems have important characteristics that determine their high conservation value, largely due to geographic isolation, which favors biodiversity due to their genetic isolation (Cabral *et al.* 2019). This isolation has caused a high degree of endemism both in plant and animal biota. As a result, islands are considered priority fragile ecosystems and critical areas in terms of conservation (Caujapé-Castells *et al.* 2010, Médail 2017).

There are 922 insular areas (islands, islets, and rocks) in the Gulf of California, which host 90 endemic plant and animal species, including 60 endemic reptile species (Lluch-Cota *et al.* 2007). Some of these islands form part of the Migratory Bird and Wildlife Refuge and Wildlife Refuge Area decreed in 1978 (Brusca 2010, Blázquez *et al.* 2018). The Gulf of California, in its entire context (marine and terrestrial), is a priority area for conservation of biodiversity (Álvarez-Castañeda *et al.* 2006), due to the high number of endemism, the occurrence of migratory birds and species of economic and ecological importance (Riley and McGlaughlin 2016). Likewise, it is the habitat of numerous species of plants and animals, considered an ecologically rich insular ecosystem (Wilder *et al.* 2008, Felger *et al.* 2011).

Even though Monserrat Island it is not inhabited and has scarce vegetation, it presents threats due to the increased human activity on land and surrounding waters (Morzaria-Luna *et al.* 2018). Knowledge and identification of the most vulnerable resources present in this desert island, as well as the relationships they maintain with their environment: climate, soil, and topography (geoforms), is necessary to allow the continuation of biological and evolutionary processes in the island under conditions of minimum human interference, to implement conservation programs in this area. Of the studies that have dealt with the flora of the Gulf of California's islands, there are those referring to taxonomic and descriptive aspects, resulting in information of great value, which provides floristic lists and description of plant communities (Felger *et al.* 2011, Velarde *et al.* 2014). However, knowledge of the distribution of plant species on different geoforms of these islands is incomplete. The objective of this study was to characterize the diversity, abundance, and distribution of plants present on Monserrat Island and to identify environmental, soil, and topography variables affecting plant distribution.

MATERIALS AND METHODS

Study site

The Monserrat island (25° 41' 00" N and 111° 03' 00" W) has an area of 19.9 km^2. It is located 13.7 km from the Baja California peninsula with an elevation of 223 masl (Álvarez-Castañeda and Cortés-Calva 2002, Figure 1). A mountain chain runs along the island, which forms two slopes: the western one is more pronounced and the eastern slope is steeper. This tendency is best observed in the southern part of the island, where the highest hill is located (223 masl). The island presents stony beaches; the only sandy beach is located in the north, with an extension of approximately 1 km in length.

The soil of the island is poorly developed and only a few centimeters thick; only in the areas where streams flow to the sea, there is sandy soil with an organic substrate of approximately 10 cm thick, due to the organic matter deposited in these areas. The streams are intermittent contingent upon flows occurring during the rainy season.

Marine terraces composed of marine calcareous sediments are present on the island. These are flat areas with slopes of no more than 4 degrees and rocks ranging from 0.3 to 2 m in size, these are located in high elevations of the island that cut abruptly, forming abyss. The average annual rainfall is 185 mm occurring in summer and to a lesser degree in winter. The average annual temperature is 33.02 °C. The vegetation of the island corresponds to that of the Sonoran Desert, dominated by thorny scrub and columnar cactaceae (Case *et al.* 2002).

Vegetation and terrain survey

Based on aerial photographs (scale 1: 70000), which were georeferenced in the field and 15 excursions on foot made on the island, the geomorphic structural elements were identified according

E. ISSN: 2007-901X

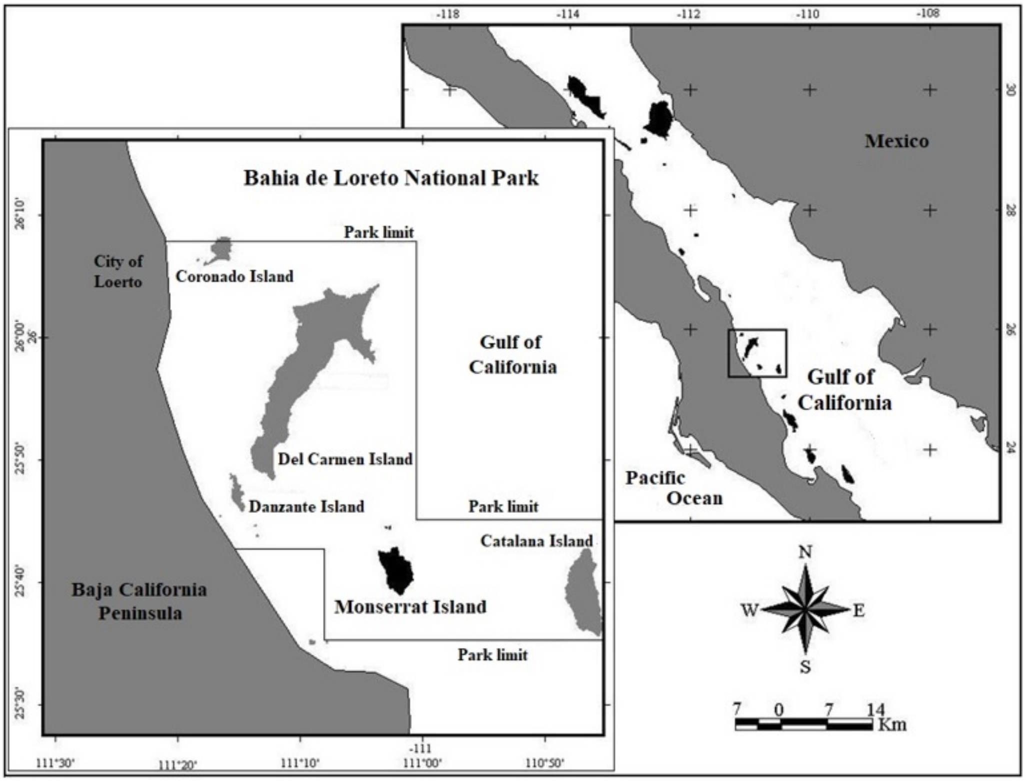

Figure 1. Location of Monserrat Island in the Gulf of California, Mexico.

to physical and structural differences of soil, slope characteristics and terrain profiles. The vegetation sampling sites were selected based on aerial photographs installing randomly 66 transects of 5 x 40 m (13 200 m^2) taking into account their geographic orientation, slope, altitude, slope exposure, and geoforms identified (Figure 2).

In each transect, the vegetation present was recorded registering the height of plants and vegetation cover. The height was taken from the ground (base of the trunk) to the highest part of the vegetation cover. The measurement of the vegetal cover (canopy) was made considering its greater diameter and the smaller diameter; then, with the formula of the ellipse = [(π) (Larger diameter) (smaller diameter) (0.25)], the area covered by the vegetation was calculated. The form of growth was recorded grouping the plants in trees (T), shrubs (S), perennial forbs (PF), succulents (SU), and climbers (C). With the use of Geographic Information Systems (GIS) and the software ArcView ver. 3.2 the analyzed information of the aerial photos, geoforms, and the types of vegetation were delimited.

Soil analysis

Soil samples (0-20 cm) were collected at the beginning of each point of transects for chemical and physical analysis. Soil texture was determined by the hydrometer method (Bouyoucos 1962), and the results were used to calculate the percentages of sand, silt, and clay. Organic matter was determined based on loss-on-ignition at 450 °C. Soil-water extracts (1:5) were set for determination of electrical conductivity (EC) and pH.

Environmental and climate analysis

For the environmental and climatic analysis, the slope (measured in degrees), orientation, solar exposure, altitude, percentage of rockiness, and geo-location (at the beginning and the end of the

E. ISSN: 2007-901X

Figure 2. Map of the Monserrat Island with routes traced on the island (yellow lines), where the vegetation transects were established (squares); the quadrats indicate the places where climatic sensors were placed for recording of precipitation, temperature and humidity (HOBBO sensors).

transect) were taken into account for each transect. To record the climatic variables, climatological sensors were established, which registered rainfall (rain gauge) and temperature and humidity of the selected sites (HOBBO® sensors, MicroDaq, Contoocook, NH, USA).

Data analysis

Species richness on the island was calculated as the average number of species per stand. The Shannon index $H' = -\sum p_i \log (p_i)$ for the relative species evenness, and Simpson index ($C = \sum p_i^2$) for the relative concentration of species dominance were calculated for the vegetation present in each geoform based on the relative cover (pi) of species (Pielou 1975). The Importance Value Index (IVI) for plant species was determined as the sum of the relative frequency, relative density, and relative dominance (Cottam and Curtis 1956). For the canonical correspondence analysis (CANOCO software, version 4), a total of 56 plant species were analyzed (Importance Value Index: IVI), 16 environmental variables in 66 sampling sites. An exploratory analysis was carried out with all biotic, abiotic, and environmental variables, to determine the association between them.

RESULTS

Overall vegetation distribution

The geoforms that were recorded on the island were: beaches, plateaus, ravines, hillsides, marine terraces, abrasion terraces, and steep slopes. The vegetation of the Monserrat Island covers most of the terrain, except the rocky beaches. The vegetation is predominantly a xerophilous scrub, in some places, the herbaceous species of the genus *Marina*, *Atriplex*, and some grasses prevail, while in other areas the predominant shrub genus are: *Gossypium*, *Jatropha*, *Encelia*, *Simmondsia*, *Fouquieria*, and *Bursera* trees, which are more abundant in areas with steep slopes.

In places with very steep slopes, the vegetation is scarcer, due to the exposure, since the exposure of the northern slope has more abundant vegetation and greater cover. The plant community is dominated by perennial and shrubby herbaceous plants, where *Jatropha cuneata* is the dominant species throughout the island (Table 1).

A sarcocaule xerophilous scrub develops mainly in ravines and bottoms of streams, where *Lysiloma candida*, *Bursera microphylla*, *Jatropha cuneata*, and climbers (*Antigonon leptopus*, *Passiflora arida*, *Janusia californica*, and *Matelea pringlei*) grow. In the bottom of ravines, the vegetation is more

E. ISSN: 2007-901X

Table 1. Number of individuals (n), average height (H), average aerial cover (AC) and importance value index (IVI) of the most important plant species recorded in the different geoforms in the Monserrat Island, Gulf of California, Mexico.

		Ravines				Other geoforms			
Plant species	Acronym	n	H(m)	AC(m^2)	IVI	N	H(m)	AC(m^2)	IVI
Antigonon leptopus	ANTLEP	1	0	5.06	0	–	–	–	–
Atriplex barclayana	ATRBAR	–	–	–	–	54	0.25	0.49	0.44
Bursera hindsiana	BURHIN	1	1.45	4.34	34.92	6	1.73	4.59	28.44
Bursera microphylla	BURMIC	18	1.89	11.11	116.82	16	1.06	3.77	14.26
Cardiospermum corindum	CARCOR	3	0.34	1.14	0.00	–	–	–	–
Carlowrightia arizonica	CARARI	9	0.94	2.10	11.00	–	–	–	–
Cercidium microphyllum	CERMIC	13	1.47	6.97	56.96	4	1.29	4.75	21.80
Parkinsonia praecox	PARPRA	19	1.15	3.97	25.37	33	0.99	2.77	9.82
Citharexylum flabellifolium	CITFLA	11	1.32	2.89	21.16	6	0.97	1.49	5.19
Cochemiea poselgeri	COCPOS	–	–	–	–	1	0.20	0.01	0
Colubrina viridis	COLVIR	31	1.84	4.14	42.27	4	1.20	3.43	14.71
Croton californicus	CROCAL	11	0.97	0.22	1.21	–	–	–	–
Desmanthus fruticosus	DESFRU	11	1.37	0.22	1.65	5	0.93	0.27	0.91
Ditaxis lanceolata	DITLAN	44	0.37	0.11	0.23	2	0.33	0.12	0.14
Encelia farinosa	ENCFAR	–	–	–	–	149	0.61	0.34	0.74
Euphorbia lomelii	EUPLOM	–	–	–	–	7	0.49	0.13	0.22
Euphorbia magdalenae	EUPMAG	4	1.66	0.25	2.29	1	0.55	0.44	0.86
Euphorbia xanti	EUPXAN	19	1.11	0.79	4.87	–	–	–	–
Fouquieria diguetii	FOUDIG	10	2.58	5.86	83.81	38	2.12	6.83	51.71
Gossypium harknessii	GOSHAR	6	0.74	1.10	4.54	58	0.90	2.32	7.45
Hibiscus denudatus	HIBDEN	25	0.52	0.72	2.08	18	0.49	0.20	0.36
Janusia californica	JANCAL	21	0.54	0.97	2.91	1	1.00	0.50	1.80
Jatropha cinerea	JATCIN	16	2.13	6.25	73.89	–	–	–	–
Jatropha cuneata	JATCUN	162	0.95	2.13	11.27	341	0.84	1.96	5.93
Jouvea pilosa	JOUPIL	–	–	–	–	10	0.32	0.91	1.04
Lippia palmeri	LIPPAL	17	0.97	0.98	5.29	–	–	–	–
Lophocereus schottii	LOPSCH	53	1.38	1.44	11.01	–	–	–	–
Lycium berlandieri	LYCBER	28	1.08	2.02	12.07	11	1.28	2.69	12.29
Lysiloma candida	LYSCAN	77	0.65	1.22	4.36	0	–	–	–
Mammillaria dioica	MAMDIO	14	0.17	0.04	0.04	34	0.14	0.01	0.00
Marina parryi	MARPAR	–	–	–	–	8	0.18	0.48	0.31
Maytenus phyllanthoides	MAYPHY	13	1.58	4.45	39.07	–	–	–	–
Olneya tesota	OLNTES	7	2.49	6.37	88.23	4	1.60	6.40	36.58
Cylindropuntia cholla	CYLCHO	14	0.54	0.17	0.49	62	0.79	1.03	2.90
Pachycereus pringlei	PACPRI	6	3.18	0.24	4.16	1	2.00	0.06	0.44
Palafoxia leucophylla	PALLEU	–	–	–	–	8	0.08	0.03	0.01
Porophyllum ochroleucum	POROCH	3	0.56	0.21	0.64	26	0.33	0.08	0.09
Simmondsia chinensis	SIMCHI	13	0.85	0.95	4.49	59	0.68	0.70	1.71
Stegnosperma halimifolium	STEHAL	2	1.10	1.92	11.76	–	–	–	–
Stenocereus gummosus	STEGUM	88	1.02	2.21	12.58	21	0.88	2.23	7.03
Stenocereus thurberi	STETHU	4	3.03	3.15	52.96	2	1.85	3.25	21.46
Viguiera deltoidea	VIGDEL	13	0.78	1.00	4.33	–	–	–	–
	Total	787				990			

abundant, presents a greater number of species, of which some are unique to the study area; the arboreal form of growth is the most abundant with *Lysiloma candida* and *Olneya tesota* attaining heights of about 5 m with aerial cover greater than 5 m^2.

Chamaephytes were the predominant life form and constituted 32% of the recorded flora, followed by therophytes (31%) and hemicryptophytes (17%). In this context, chamaephytes, hemicryptophytes, and cryptophytes altogether constituted the main bulk of the floristic structure of each of the recognized geoform unit.

We recorded 114 species, belonging to 92 genera and 38 families of vascular plants. The most abundant families were Asteraceae, Euphorbiaceae, Fabaceae, Poaceae, and Cactaceae (Table 1). The genera with the greatest diversity of species were: *Euphorbia*, *Porophyllum*, *Opuntia*, and *Perityle*. Herbaceous perennials and shrubs were the more representative forms of growth.

The desert scrub is the dominant vegetation on the island, in some places prevailing herbaceous plants such as *Marina*, *Atriplex*, and some grasses, while in other areas, the dominant plants presented are shrubs such as *Gossypium*, *Jatropha*, *Encelia*, *Simmondsia*, and *Fouquieria*. The *Bursera* trees are more abundant in areas with little steep slopes (less than 25°). On areas with steep slopes (greater than 45°), the development of vegetation is scarce. Northern exposure slopes have denser vegetation, with higher canopy cover values. Overall, the island is dominated by herbaceous perennial and shrubby species, where *Jatropha cuneata* is the dominant one.

The dominant species in ravines are *Lysiloma* candida, *Bursera microphylla*, *Jatropha cuneata*, and lianas such as *Antigonon leptopus*, *Passiflora arida*, *Janusia californica* and *Matelea pringlei*. In streams, vegetation is even more abundant, they have a greater number of species, some of which are unique to these areas; the dominant species are *Lysiloma candida* reaching about 5 m in height and *Olneya tesota* with a height of 4-5 m. In alluvial fans with a layer of higher matter contents, the vegetation is predominantly constituted by shrubs, and dominated by *Jatropha cinerea*.

The coastal scrub develops on sandy soils of the dunes at the north of the island, mainly composed of *Jouvea pilosa* and *Atriplex barclayana*, and by several annual grasses growing in the rainy season. The scrub takes varying composition and growth forms composed mainly by desert scrub and sarcocaule thickets. Marine terraces have a community of undeveloped desert scrub, averaging 50 cm tall and 1.60 m^2 canopy cover values, dominated by *Fouquieria diguetii* and *Jatropha cuneata*. Individuals of *Ferocactus digueti* were recorded only in these areas. *Rhizophora mangle* was recorded on the north coast of this island.

Vegetation transect study

A total of 5607 individuals belonging to 51 species were recorded in the 66 transects, covering an area of 13 200 m^2. Shrubs and herbaceous perennials were the most abundant species (18 and 15, respectively), followed by succulent and trees, with nine and seven species respectively, and climbing plants (two species). The most abundant species in all geoforms was *Jatropha cuneata*, with 503 individuals recorded; *Encelia farinosa* develops in plateaus with little slope (less than 10°), being more abundant in the north part of the island; *Stenocereus gumosus* develops in patches, covering large areas, mainly on the slopes with little inclination (15-20°) to the east and north side of the island; *Lysiloma candida* was typical of streams and ravines, being one of the few tree species in the island.

Table 2. Comparison of the diversity indexes recorded from ravines and other geoforms in the Monserrat Island, Gulf of California, Mexico.

Indices	Ravines	Other geomorphic structures
Richness (S)	35	30
Abundance (N)	787	990
Shannon's diversity (H')	2.97	2.41
Maximum diversity (H'_{max})	3.56	3.40
Species evenness (J´)	0.84	0.71
Simpson's Index (D)	0.082	0.161

The Shannon-Wiener index showed high diversity in the island (H = 2.95, Table 2); the distribution of vegetation is heterogeneous as well as the growth form, it varies depending on environmental conditions prevailing in each microenvironmental geoform. The highest important values recorded include the arboreal species: *Fouquieria diguetii*, *Olneya tesota*, *Jatropha cinerea*, *Bursera microphylla*, *Cercidium microphyllum*, *Stenocereus thurberi*, *Bursera hindsiana*, *Colubrina viridis* and *Maytenus phyllanthoides*, developed above the middle vegetation, and characterizing the desert scrub on the island. Pseudonodricism was observed in some of these species (*J. cinerea*, *B. microphylla*, *C. microphyllum*, and *B. hindsiana*). *Pachycereus pringlei*, *Stenocereus thurberi*, *Fouquieria diguetii*, *Olneya tesota* and *Jatropha cinerea* are the dominant species and protrude above the rest of them in the vertical stratum, however, in the glens, *Lysiloma candida* reaches heights up to 5 m tall, with high rates of regeneration.

Table 3 shows results of the canonical correspondence analysis, cumulative variance, and Monte Carlo permutation of the biotic variables of the

E. ISSN: 2007-901X

Table 3. Results of the canonical correspondence analysis, cumulative variance and Monte Carlo permutation of the biotic variables of the plant species (Importance Value Index); the environmental variables (16) and 66 vegetation transects, registered for the Monserrat island, Gulf of California, Mexico.

Axis	1	2	3	4	Total inertia
Eigenvalues	0.401	0.382	0.299	0.266	9.326
Biotic-environmental correlations	0.776	0.798	0.720	0.739	
Accumulated variance, %					
Biotics data of plant species	4.3	8.4	11.6	14.5	
Biotic-environment association	16.3	31.9	44.0	54.8	
Monte Carlo permutation test					
F = 2.202; p = 0.506	0.401				

plant species on Monserrat Island. Analysis of the structural composition of ravines showed more abundant vegetation, where the height average was 1.6 m, and the canopy cover was 4.19 m^2 and is dominated by *Lysiloma candida*, *J. cuneata*, *Colubrina viridis*, *Cerciduim praecox*, and *C. microphyllum*; during the rainy season, climbing species such as *Antigonon leptopus* and *Cardiospermum corindum* grow abundantly on the canopies of other species in these sites. The other geoforms (beaches, plateaus, marine terraces, and slopes), the vegetation reaches an average height of 93.1 cm and a canopy of 2.6 m^2.

Figure 3 shows the canonical map of correspondence. The total inertia obtained was 9.32, indicating that the data present a high heterogeneity in their values (both biotic and environmental variables) and that they are suitable for a canonical correspondence analysis, the results in the Monte Carlo permutation test (0.30) indicate a high correlation between the variables analyzed (biotic vs environmental).

The canonical correspondence graph shows a differential gradient of the environmental variables of slope, soil, exposure, and altitude; three large groups were detected, the slope is the most influential in some plant species; while soil and exposure variables have less effect on plant species. However, more species are associated with these; the height has a low influence among all the environmental variables, but it has an influence on plant species of ecological relevance such as *Olneya tesota*, which grows in high places of the island, mainly in geoforms of plateaus and places with gentle slopes.

The most evident association was between the bare soil and hillside exposure, the latter characterized by the north and south exposures, given that the island has an orographic composition in which most of the slopes are oriented towards these courses, being the south-facing exposures with poor coverage, due to their orientation characteristics (southern exposure slopes are more "dry" than those on the north side).

DISCUSSION

Overall vegetation distribution

Out of the 114 plant species registered on the Island, 34 (28.9%) are endemic to the Baja California peninsula and nearby islands and two species to the islands; five genera are monospecific and 16 are reported as having only one species for the island and the Baja California peninsula (Case *et al.* 2002). Two species found on the island and the peninsula are listed in the NOM-059-SEMARNAT-2001, while the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) listed 12 species for the island, 11 of them are cacti. Due to the abrupt terrain in most of the island, the ravines have an important role in the development of the vegetation because it is in these sites where most of the vegetation grow.

Jatropha cuneata appears to be generalists because it was found in almost all geoforms. This means that a threshold for extreme exposure, nutrient impoverishment of soil, did not exist on the island for this shrub. *J. cuneata* presents a rapid response to

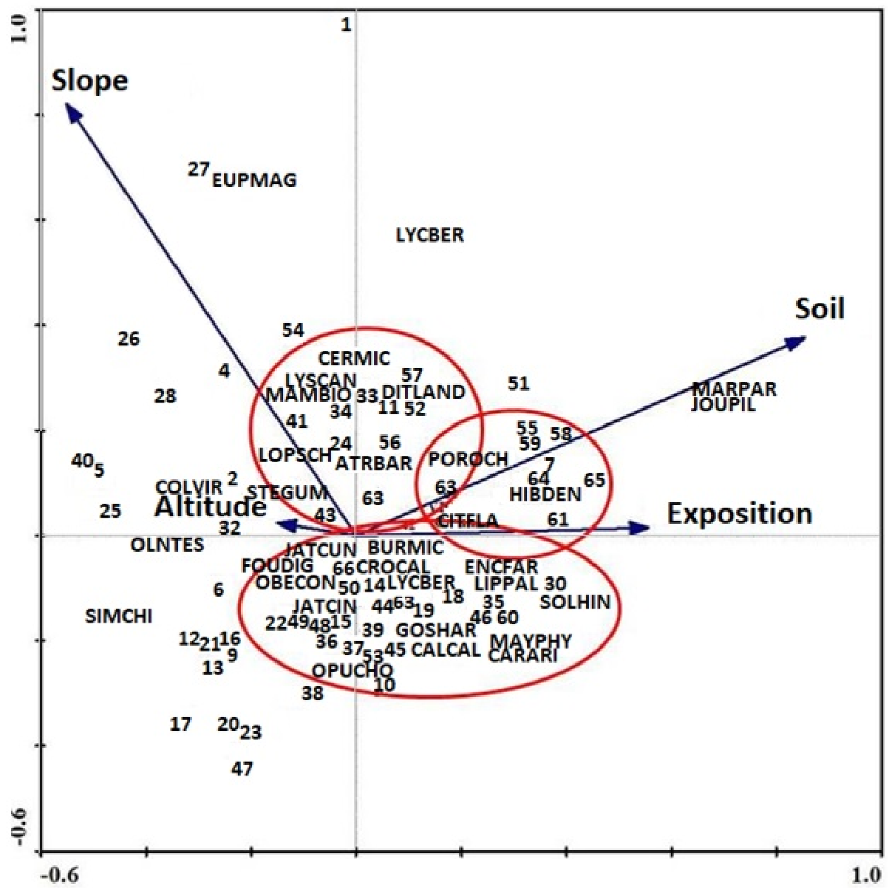

Figure 3. Analysis of canonical correspondence with plant species, importance value index (IVI) and the most significant environmental variables in 66 vegetation transects on the Monserrat Island, Gulf of California, Mexico.

humidity since they produce their leaves after the first rainfall, regardless of its seasonal occurrence (Maya and Arriaga 1996). Thus, this plant appears to depend on the combination of water availability and high temperature to complete its phenological cycle and produce sexual structures.

Vegetation transect study

A moderate level of species richness was found in the island. The level of diversity on this island surpasses the number of species found in smaller neighboring xeric islands of the Gulf of California receiving less than 200 mm of rainfall, such as Alcatraz (55 plant species), Dátil (102 plant species), Patos (13 plant species), and Cholludo (28 plant species), but it presents a comparable richness to the San Esteban Island (41 km^2, 122 plant species) (Wilder *et al.* 2008).

Different from most other descriptions of desert vegetation in islands in the Gulf of California, we have endeavored here to analyze the vegetation patterns on Monserat Island taking into account the geoforms detected in this ecosystem. Exposition, altitude, soil characteristics, and slope seemed to increase the environmental variation across the island, which resulted in a rather distinctive species' segregation. Also the causal relations between site characteristics and vegetation distribution were determined by standard multivariate techniques. For instance, slope was far more reliably measure for describing vegetation distribution than altitude, although, the latter variable influences *Olneya tesota*, a plant species ecologi-

E. ISSN: 2007-901X

cally relevant in this landscape because it creates microhabitats that benefit many species of flora and fauna (Carrillo-García *et al*. 1999), and therefore is a valuable nurse species (Suzán *et al*. 1996). Although the highest point in Monserrat Island was only 223 m, lower temperatures at higher altitudes imply a greater adaptation of this tree to cooler temperatures.

Euphorbia magdalenae was strongly associated with slope, which agrees with description of this shrub in islands of the Gulf of California where this plant grows on rocky hillsides or ridge crest of these islands (Felger *et al*. 2012). The distribution of both *Jouvea pilosa* and *Marina parryi* was influenced by soil characteristics. The grass *Jouvea pilosa* grows on dunes, which means that it prosper on deeper soil (Romero-Lopez *et al*. 2006) than the rocky spots on the island. *Rhizophora mangle* inhabits the north coast of this island and its growth is due to the very high salinity of its stands, shallow water table, and poor aeration and drainage.

The high species diversity on the island seems to be related to the low salinity of its soil and/or heterogeneity of the topography, which supports clumps of grasses, trees, succulent life forms, and ephemerals during the rainy season. The vegetation and environment of Monserrat Island are alike to those described for other desert islands of the Gulf of Baja California (Felger *et al*. 2012). All are dry and dominated by maritime exposure and subjected to isolation which has fostered biological endemism. *Salvia platychelia* and *Ferocactus diguetii* are of particular note as they are narrow-endemics, so far having only been recorded in the sea of Cortez Islands.

The Monserrat Island presents a topography (geoforms) that give a particular character to the development of its vegetation, which is not different from that which is developed in most of the peninsula of Baja California Sur, Mexico, being considered, together with most of the other islands of the Gulf, as short-term and localized disturbances (Tershy *et al*. 1997). The geographic isolation of this island has caused, to a greater or lesser extent, biodiversity to be genetically isolated (Salm and Clark 1994), which has favored high endemism of plants. Since the abiotic and biotic factors of the islands of the Gulf of California are unique to each island, it was not surprising to find a great diversity of flora on the island under study, as has occurred on other islands in this region (Wilder *et al*. 2008).

In this context, the plant species present on the island are sensitive to man damage and natural events, such as hurricanes. Although the literature that relates geomorphology and flora is still scarce, their relationship is evident, which implies a greater understanding of ecosystems and the development processes of plant communities. In this sense, Radhakrishnan *et al*. (1998) and Zinck (2016) point out the importance of geoforms in the study of vegetation and its adaptation and development processes as a new strategy for research and conservation of island ecosystems. On the other hand, McAuliffe *et al*. (1991, 1994) showed the importance of the relationship between vegetation and geoforms in continental regions.

The results showed that the ravines and streams of the island present the highest diversity indexes, abundance of species and morphometric averages, as well as unique species, it is worth mentioning that these geoforms are the ones that present greater anthropic activity, mostly by fishermen, who use the resource, mainly for fuel. The damage that these activities have on these geoforms and the vegetation they sustain is not known, so these can be considered as critical areas. This study serves as a basis for understanding the processes of adaptation and distribution of plant communities under particular geomorphic conditions, as is the case of the islands of the Gulf of Cortez. Thus, abiotic and in particular geological features are important to consider in planning conservation projects (Groves *et al*. 2002, Strasberg *et al*. 2005).

CONCLUSIONS

The distinctive mix of xeric species makes Monserrat Island unique due to the high presence of endemic plants (28%) and distribution patterns in a geomorphic system composed of beaches, plateaus, ravines, hillsides, marine terraces, abrasion terraces, and steep slopes. As in the majority of the islands of the Gulf of California, the most developed vegetation community is found in the ravines; the most common species here are *L. candida*, *J. cuneata*, *C. viridis*, *C. praecox*, and *C. microphyllum*. The primary axis of variation within the vegetation of Monserrat Island is a function of soil characteristics, altitude, slope and exposition.

LITERATURE CITED

Álvarez-Castañeda ST, Cortés-Calva P (2002) Extirpation of bailey's pocket mouse, *Chaetodipus baileyi fornicatus* (heteromyidae: mammalia), from Isla Montserrat, Baja California Sur, Mexico. Western North American Naturalist 62: 496-497.

Álvarez-Castañeda ST, Cortés-Calva P, Méndez L, Ortega-Rubio A (2006) Development in the sea of Cortés calls for mitigation. BioScience 56: 825-829.

Blázquez MC, Vázquez P, Ortega-Rubio A (2018) Status of the phylogeography, taxonomy and conservation of the reptiles of the Gulf of California islands. In Mexican Natural Resources Management and Biodiversity Conservation: Recent Case Studies. Springer International Publishing. Switzerland. pp: 285-304.

Bouyoucos GJ (1962) Hydrometer method improved for making particle size analysis of soil. Journal of Agronomy 54: 464-465.

Brusca RC (2010) The Gulf of California: Biodiversity and Conservation, University of Arizona Press. USA. pp: 168-187.

Cabral JS, Wiegand K, Kreft H (2019) Interactions between ecological, evolutionary and environmental processes unveil complex dynamics of insular plant diversity. Journal of Biogeography 46: 1582-1597.

Carrillo-García A, León De La Luz JL, Bashan Y, Bethlenfalvay GJ (1999) Nurse plants, mycorrhizae, and plant establishment in a disturbed area of the Sonoran Desert. Restoration Ecology 7: 321-335.

Case TJ, Cody ML, Ezcurra E (2002) A New Island Biogeography of the Sea of Cortés. Oxford University Press. Oxford, UK. 690p.

Caujapé-Castells J, Tye A, Crawford DJ, Santos-Guerra A., Sakai A, Beaver K, Cottam G, Curtis JT (1956) The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Cottam G, Curtis JT (1956) The use of distance measurement in phytosociological sampling. Ecology 37: 451-460.

Felger RS, Wilder BT, and Gallo-Reynoso JP (2011) Floristic diversity and long-term vegetation dynamics of San Pedro Nolasco Island, Gulf of California, Mexico. Natural History 43: 1-42.

Felger RS, Wilder BT, Romero-Morales H (2012) Plant Life of a Desert Archipelago: Flora of the Sonoran Islands in the Gulf of California. The University of Arizona Press. Tucson, AZ, USA. 624p.

Gillespie RG, Claridge EM, Roderick GK (2008) Biodiversity dynamics in isolated island communities: interaction between natural and human-mediated processes. Molecular Ecology 17: 45-57.

Groves CR, Jensen DB, Valutis LL, Redford KH, Shaffer ML, Scott JM, Baumgartner JV, Higgins JV, Beck MW, Anderson MG (2002) Planning for biodiversity conservation: putting conservation science into practice: A seven-step framework for developing regional plans to conserve biological diversity, based upon principles of conservation biology and ecology, is being used extensively by the nature conservancy to identify priority areas for conservation. BioScience 52: 499-512.

E. ISSN: 2007-901X

Lluch-Cota SE, Aragón-Noriega EA, Arreguín-Sánchez F, Aurioles-Gamboa D, Bautista-Romero JJ, Brusca RC, Cervantes-Duarte R, Cortés-Altamirano R, Del Monte-Luna P, Esquivel-Herrera A., Fernández G., Hendrickx ME, Hernández-Vázquez S, Herrera-Cervantes H, Kahru M, Lavín M, Lluch-Belda D, Lluch-Cota DB, López-Martínez J, Marinote SG, Nevárez-Martínez MO, Ortega-García S, Palacios-Castro E, Parés-Sierra A, Ponce-Díaz G, Ramírez-Rodríguez M, Salinas-Zavala CA, Schwartzlos RA, Sierra-Beltrán AP (2007) The Gulf of California: review of ecosystem status and sustainability challenges. Progress in Oceanography 73: 1-26.

Lobin W, Florens FBV, Moura M, Jardim R, Gómes I, Kueffer C (2010) Conservation of oceanic island floras: Present and future global challenges. Perspectives in Plant Ecology, Evolution and Systematics 12: 107-129.

Maya Y, Arriaga L (1996) Litterfall and phenological patterns of the dominant overstorey species of a desert scrub community in north-western Mexico. Journal of Arid Environments 34: 23-35.

McAuliffe JR (1991) Demographic shifts and plant succession along a late Holocene Soil chronosequence in the Sonoran Desert of Baja California. Journal of Arid Environments 20: 165-178.

McAuliffe JR (1994) Landscape evolution, soil formation and ecological patterns and processes in Sonoran Desert Bajadas. Ecological Monographs 64: 11-148.

Médail F (2017) The specific vulnerability of plant biodiversity and vegetation on Mediterranean islands in the face of global change. Regional Environmental Change 17: 1775-1790.

Morzaria-Luna HN, Cruz-Piñón G, Brusca RC, López-Ortiz AM, Moreno-Báez M, Reyes-Bonilla H, Turk-Boyer P (2018) Biodiversity hotspots are not congruent with conservation areas in the Gulf of California. Biodiversity and Conservation 27: 3819-3842.

Peinado M, Delgadillo J, Aguirre JL (2005) Plant associations of El Vizcaino biosphere reserve, Baja California Sur, Mexico. The Southwestern Naturalist 50: 129-149.

Pielou EC (1975) Ecological Diversity. New York: Wiley Interscience. USA. 165p.

Radhakrishnan K, Pandurangan AG, Rajasekharan S, Pushpangadan P (1998) Ecofloristic studies of Lakshadweep Islands, India. Journal of Economic and Taxonomic Botany 22: 37-48.

Riley L, McGlaughlin ME (2016) Endemism in native floras of California's Channel Islands correlated with seasonal patterns of aeolian processes. Botany 94: 65-72.

Romero-Lopez BE, León de la Luz JL, De La Cruz-Agüero G, Pérez-Navarro JJ (2006) Estructura y composición de la vegetación de la barra costera El Mogote, Baja California Sur, México. Boletín de La Sociedad Botánica de México 79: 21-32.

Salm R, Clark R (1994) A Guide for Managing Marine Protected Area. I. U. C. N. Gland, Switzerland. 222p.

Strasberg D, Rouget M, Richardson DM, Baret S, Dupont J, Cowling RM (2005) An assessment of habitat diversity and transformation on la Réunion Island (mascarene islands, Indian ocean) as a basis for identifying broad-scale conservation priorities. Biodiversity and Conservation 14: 3015-3032.

Suzán H, Nabhan GP, Patten DT (1996) The importance of *Olneya tesota* as a nurse plant in the Sonoran Desert. Journal of Vegetation Science 7: 635-644.

Tershy BR, Breese D, Croll DA (1997) Human perturbations and conservation strategies for San Pedro Martir Island, Islas del Golfo de California Reserve, Mexico. Environmental Conservation 24: 261-270.

Velarde E, Wilder BT, Felger RS, Ezcurra E (2014) Floristic diversity and dynamics of Isla Rasa, gulf of California-A globally important seabird island. Botanical Sciences 92: 89-101.

Wilder BT, Felger RS, Romero-Morales H (2008) Succulent plant diversity of the Sonoran Islands, Gulf of California, Mexico. Haseltonia 14: 127-160.

Zinck JA (2016) The Geomorphic Landscape: Criteria for classifying geoforms. In: Zinck JA, Metternicht G, Bocco G, Del Valle HF (eds) Geopedology. Springer International Publishing. Switzerland. pp: 77-99.

E. ISSN: 2007-901X