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VEGETATION OF THE SANTA CATALINA MOUNTAINS, ARIZONA: A GRADIENT ANALYSIS OF THE SOUTH SLOPE[1]

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Abstract. Vegetation of the southwest slope of the Santa Catalina Mountains of southeastern Arizona was sampled and transects prepared for 1,000-ft (305 m) elevation belts on granite and gneiss soils from the summit forests (2,440-2,750 m) to the base of the mountains (900 m). Transects also represented subalpine forests above 2,750 m in the Pinaleno Mts. and vegetation of the valley plain or bajada below the mountains, and samples were taken from volcanic soils below 900 m in the Tucson Mts.

Principal community-types from high elevations to low are: subalpine forest (*Picea engelmanni* in the Pinaleno Mts. and *Abies lasiocarpa*), montane fir forest (*Abies concolor, Pseudotsuga menziesii*), pine forests (*Pinus ponderosa, P. strobiformis*), pine-oak forests (*P. ponderosa, Quercus hypoleucoides*), pine-oak woodlands (*P. ponderosa, P. chihuahuana, Q. hypoleucoides, Q. arizonica*), pygmy conifer-oak scrub (*Pinus cembroides, Juniperus deppeana, Q. arizonica, Q. emoryi, Arctostaphylos pringlei, A. pungens,* monocot shrubs), open oak woodland (*Q. emoryi, Q. oblongifolia, Vauquelinia californica,* monocot shrubs, and grasses), desert-grassland (*Agave schottii, Haplopappus laricifolius,* and grasses), Sonoran desert of mountain slopes (north-slope shrub phase, and south-slope spinose-suffrutescent phase), upper bajada desert (*Cercidium microphyllum, Franseria deltoidea*), and lower bajada desert (*Larrea tridentata*). Forests of canyons and arroyos are also described. Relations of communities to elevation and topographic moisture gradients are represented in a mosaic chart.

Physiognomic relations of communities are represented in charts of growth-form coverage in relation to elevation and topographic moisture gradients. Growth-form diversity increases from high-elevation forests strongly dominated by evergreen-needleleaf trees to desert of lower mountain slopes in which pinnate leguminous trees, spinose shrubs, suffrutescent semi-shrubs, and stem-succulents share dominance.

Among Raunkiaer life-forms hemicryptophyte species are most numerous at middle and higher elevations, phanerophyte species at lower elevations. In open oak woodlands and desert grasslands phanerophytes, hemicryptophytes, and suffrutescent chamaephytes each make up about one-third of the perennial flora. Desert floras of mountain slopes are characterized by predominance of suffrutescent chamaephytes over both phanerophytes and hemicryptophytes, and large numbers of therophyte species.

Analysis in terms of geographic areas of species shows decreasing numbers of Rocky Mountain, Western, and Northern species from high-elevation forests downward, increasing numbers of Southwestern and Latin American species at lower elevations. Madrean species of the

[1] This is the third paper from a project, "A study of southwestern mountain vegetation," supported by the National Science Foundation.

Mexican Plateau and Southwestern species predominate in pine-oak forests and woodlands and pygmy conifer-oak scrub. Sonoran, Chihuahuan, and Latin American species predominate in the desert of lower mountain slopes, and widely distributed Southwestern species in the *Larrea* desert.

Flora of the Catalina Mountains is rich and community species diversities are high. Species diversities increase toward lower elevations; desert-grasslands and deserts of lower mountain slopes are among the richest communities in the United States. Floristic diversity is higher in continental than maritime climates, as indicated by comparison of species diversities and community differentiation along topographic moisture gradients in the Catalinas and in California mountains.

Introduction

Purpose of study

Mountain ranges of the Southwest are of special interest for their complex patterns of natural communities interrelating the floras and faunas of Mexico and the United States. One of these ranges, the Santa Catalina Mountains of southeastern Arizona, subject of a classic study by Shreve (1915), is of singular attractiveness as a research area for its combination of wide range of elevation and communities, relative freedom from disturbance, and location and accessibility. The present study is an analysis of the vegetation of the southwest slope of that range, investigating the relations of species and communities to one another in the vegetation pattern, describing the plant communities, and comparing them in terms of growth-forms and life-forms, geographic relationships, and species diversities.

Geology

A great area of the western United States, the Basin and Range Province, is characterized by north-south mountain ranges and intervening desert basins (Fenneman 1931). Such desert range and basin topography characterizes the southern half of Arizona, south of the Mogollon Rim bounding the Colorado Plateau. Within the southern part of the Basin and Range Province, the southwestern corner of Arizona (along with part of southeastern California and southern Nevada and much of Sonora) is distinguished as the Sonoran Desert Section, with desert bolsons of elevations decreasing from around 1,000 m in the east to sea level at the Gulf of California and scattered mountain ranges forming about 20% of the surface (Ransome 1916, Fenneman 1931, Wilson 1962). East and north of a line curving from Nogales past Tucson and Phoenix to the Colorado River, and extending eastward to west Texas and southward in Mexico, is the Mountain Section (Ransome 1916, Fenneman 1931) or Mexican Plateau (Atwood 1940). The Arizona portion of the Mexican Plateau is an area of taller mountains with major ranges approaching or exceeding 3,000 m elevation, the mountains occupying about 50% of the surface and semi-bolson valleys the remainder. Major ranges of this section in Arizona include the Santa Catalina, Pinaleno (Graham), Chiricahua, Santa Rita, and Huachuca Mountains. Of these the Santa Catalinas, together with the Tortilla Mountains north of them and the Rincon and Santa Rita Mountains south, form the western rampart of the Mexican Plateau Section in Arizona.

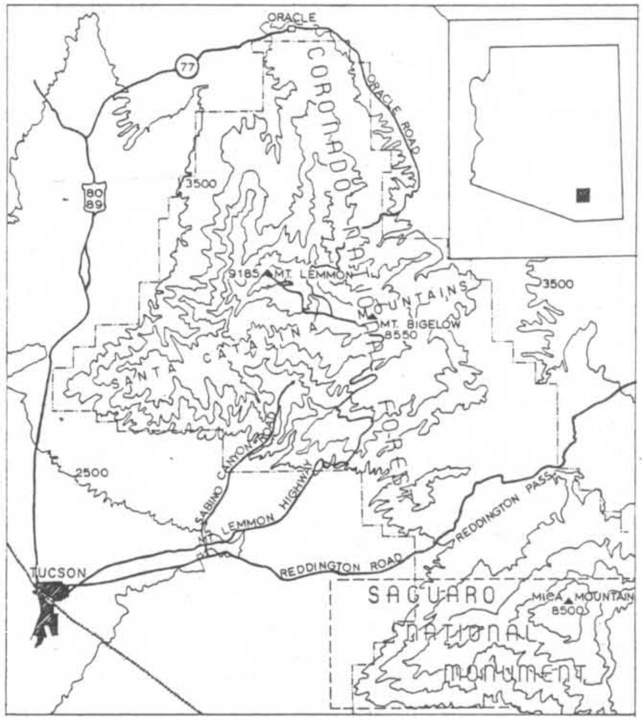

FIG. 1. The Santa Catalina Mountains and (insert) their location in Arizona.

The Santa Catalina Mountains (Fig. 1) are roughly triangular in shape; the east-west base of the triangle is about 32 km, and the apex is about 32 km north of that base. The southern and western sides of the triangle probably represent fault lines along which the mountains were lifted. Elevations range from the summits of Mt. Lemmon and Mt. Bigelow at 2,766 and 2,608 m down to 850-980 m at the southwestern base of the range near Tucson. The mountains rise steeply to the summits of a forerange of lower mountains cut by deep canyons; behind the forerange lies a chain of valleys including Molino Basin in the main study area. Behind these valleys the mountains again rise steeply, with areas of outcrop and rock spires, to a dissected upland of lower relief above 2,100 m, interpreted by Davis (1925, 1931) as the Powell surface of an earlier cycle of erosion. Mt. Lemmon, the high point of the range, rises above the upland as a residual mound on the former lowland.

Over most of the southern slope of the Catalinas the parent material is the Catalina gneiss complex, grading from granite and granitic gneiss near the summit downward through augen gneiss to banded augen gneiss near the southwestern base of the mountains (Moore et al. 1941, Bromfield 1952, Du Bois 1959b, Wilson et al. 1960). Other rocks including Older Precambrian Oracle granite and Pinal schist, Younger Precambrian Apache

Group sedimentaries, and Cambrian Troy quartzite outcrop along the crest of the range; Carboniferous limestone, Cretaceous andesite, and diabase outcrop on the northwest slope of the range (Moore et al. 1941, Du Bois 1959a, Wilson et al. 1960).

The Catalina gneiss forms a narrow and localized rock platform, or exposed pediment along the south edge of the range (Tuan 1959). Sediments of complex history cover the remainder of the pediment and fill the Santa Cruz Valley to great depth. The surface of these sediments forms the bajada or valley plain, which slopes with an average inclination of about 3° from the mountains to Tucson at 730 m elevation in the Santa Cruz Valley. The present study is designed as a transect on the Catalina gneiss from the pediment upward to near the summits of the mountains. The transect was extended downward on the bajada sediments to Tucson and upward to the summit of Mt. Lemmon on granite and other rocks not supporting noticeably different vegetation. The study was also extended upward from 2,750 to 3,230 m on the granite gneiss of the Pinaleno range to the northeast of the Catalinas, and comparative samples were taken from volcanic rocks of the Tucson Mountains (Bryant 1952) to the west.

Climate

The lowlands of the Basin and Range Province in Arizona have semiarid to arid climates with two rainy seasons, one from December to March, the other from July to September (Smith 1956, Sellers 1960). The winter rainfall results from cyclonic storms from the Pacific Ocean; the summer rainfall is convective and results from the establishment, about the first of July in most summers, of a monsoonal flow drawing relatively moist and conditionally unstable air from the Gulf of Mexico around the southwest side of a westward extension of the Bermuda High through Mexico into Arizona (Bryson and Lowry 1955, Sellers 1960). The rainfall is quite variable from year to year. McDonald (1956) obtained coefficients of variation for total annual precipitation of 0.30 and 0.29 for Tucson and Oracle, and 0.62 for Yuma to the southwest, compared with values of 0.16-0.19 for such more humid climates as those of Boston, Maine, Cleveland, Ohio, and Portland, Oregon. The summer rainfall is more variable from station to station in a given season (Humphrey 1933, McDonald 1956), the winter rainfall is more variable from year to year in a given place (McDonald 1956) but more effective in increasing soil moisture (Shreve 1934). Mean annual precipitations at Tucson on the southwest and Oracle (at 1,370 m) on the northeast side of the Santa Catalina Mountains are 27.8 cm (with 57% in summer, May to October), and 49.2 cm (with 48% in summer, McDonald 1956). The mountains are in the transition between arid climates with winter rain exceeding summer rain to the west, and semiarid climates with summer rain predominant to the east and south.

Incomplete records of precipitation at higher elevations in the Catalina Mountains include an average annual precipitation of 85 cm for 6 years at Soldiers Camp, 2,400 m (Mallery 1936), and 81 cm for 3 years on Mt. Lemmon summit, 2,770 m (Weather Bureau 1952-54). The 3-year study of Shreve (1915) showed a precipitation increase from 19 cm at 915 m to 42-47 cm at 2,320 and 2,440 m. Turnage and Mallery (1941, cf. Schwalen 1942) found that summer rainfall increased by 1.60 cm per 100 m elevation, winter rainfall by 1.30 cm per 100 m. Data from a 3-year study of precipitation in a grid of 28 guages in the Catalina Mts. show an increase of daily precipitation during the summer season (July and August) of 0.225 cm per 1,000 m from the base of the mountains to the upland above 2,000 m, and no significant increase with elevation above 2,000 m (personal communication, L. J. Battan, Institute of Atmospheric Physics, University of Arizona).

Mean monthly temperatures for January and July and mean annual temperatures are 10.0, 30.1, and 19.6°C for Tucson and 7.7, 26.5, and 16.7°C for Oracle (Sellers 1960). Shreve's (1915) data gave an average decrease of temperature with elevation of 7.5°C/1,000 m. Soil temperatures at 20-cm depths have been taken across the mountains from Oracle to Tucson in an annual cycle. Summer temperatures decrease more steeply with elevation on the bajada than on the mountain slopes; winter temperatures show a strong inversion from the base of the mountains down the bajada and decrease more rapidly with elevation on the Powell surface upland above 2,100 m than on the mountain slopes between 900 and 2,100 m.

Soil

Soils of the Tucson area are described by Youngs (1931). The bajada soils show gradation from coarse and porous soils of the upper to fine and relatively impermeable soils of the lower bajada. Toward the lower bajada gravel and rock content decrease, silt and clay content increase, capillary water increases and availability to plants decreases, and soluble salts increase (Yang and Lowe 1956, Yang 1957). Caliche, an irregular, impermeable layer of calcium carbonate, is frequent in bajada soils (Breazeale and Smith 1930, Youngs 1931). Soils of the Catalinas above the bajada are mostly shallow lithosols, with increasing organic matter, decreasing pH, and other gradients toward higher elevations (personal communication S. W. Buol) paralleling the soil gradation in the Pinaleno Mts. studied by Martin and Fletcher (1943). As classified by soil groups the soils of the Pinalenos gradated upward from red desert soils in the desert scrub through reddish brown soils in the desert grassland and shantung brown soils in the oak woodland to gray-brown podsols in the coniferous forest. Summer soil-moisture contents measured in the Catalinas by Shreve (1915) showed little change (around 2-3% of dry weight) below 2,100 m, but increased rapidly above this to 9% on a south and 28% on a north slope at 2,750 m.

History

Presence of Indians in southern Arizona goes back 10,000 years or more; during the first half of the present millennium the Hohokam people occupied valley sites, including that of Tucson, with farming settlements. The Indians of historic time were two groups with divergent ways of life (Spicer 1962)—the agricultural Pima Indians in the river valleys and the primarily non-agricultural, marauding Apaches in the mountains. A narrow salient of Spanish civilization was extended down the Santa Cruz Valley from Sonora into Arizona by the missionary-explorer Father Kino and his successors, following exploratory trips in 1692-1700. The mission at San Xavier del Bac was established near Tucson in 1732 (Hamilton 1884, Bancroft 1889, Bryan 1925, Spicer 1962). The Santa Cruz missions carried on farming, cattle raising, and limited mining, but Spanish control crumbled after 1820 in consequence of internal disorganization accompanying the Mexican war of independence and external aggression by the Apaches.

American beaver trappers began entering Arizona about 1825-26 (Bryan 1925), and Arizona became part of the United States in consequence of the Mexican war of 1848 and the Gadsden purchase of 1853. Following the war, arrival of railroads, and subjugation of the Apaches in 1870, the area was open for more effective settlement. Ranchers grazed extensive herds of cattle and sheep in the Santa Cruz valley in the 1880's and, as range productivity of the valley decreased, spread increasingly into other areas. Grazing in Arizona was a favored scheme of quick wealth (Hamilton 1884), and maximum numbers of cattle were brought in for unrestricted, competitive grazing (Thornber 1910, Wagoner 1952). The consequences to the Santa Cruz and San Pedro Valleys are a matter of historic record (Griffiths 1901, Smith 1910, Thornber 1910, Thornthwaite et al. 1942, Hastings 1959, 1963); other valleys have had comparable histories.

The Santa Cruz Valley before 1870 (Smith 1910, Thornber 1910) had in the central valley an open forest of *Populus, Fraxinus, Salix*, and *Juglans*, and beyond this were woodlands of mesquite (*Prosopis juliflora*); grasses formed undergrowth in the forests and meadows beyond them. Reduction of plant cover by grazing had the dual effects of increasing runoff from mountain slopes while rendering the valley more vulnerable to erosion by the larger volumes of water. Floods of new intensity reached the valley, eroding deep channels or arroyos, uprooting trees of the valley forest and lowering the water table supporting other valley vegetation. Effects of cattle up to 1890 were intensified by the drought of 1891-93 (Thornthwaite et al. 1942). The possibility that climatic change has been at least partly responsible for arroyo cutting in the Southwest has been discussed by several authors (cited by Niering et al. 1963). Other effects of grazing, fire control, and lowered water tables on Arizona range lands are discussed by Griffiths (1901), Thornber (1910), Bryan (1928), Humphrey (1958, 1960), and Hastings (1959, 1963).

The bajada down which the transect extended has been modified by grazing and other forces. The central valley is occupied by the city of Tucson. Areas studied along the Mt. Lemmon highway believed to have been desert grassland are now cactus scrub or mesquite desert with *Gutierrezia* in which saguaro is failing to reproduce (Niering et al. 1963). The *Cercidium-Franseria* and *Larrea* deserts have been affected less severely, but grass cover has probably been reduced. The desert between Tucson and the Santa Catalina Mountains is now being subdivided for housing as fast as real estate promotion will permit.

The greater part of the mountains themselves have been forest reserve since 1902 and part of Coronado National Forest since 1908. Lower mountain slopes are grazed as private land or by Forest Service permit; but the area of the present study including the Sabino Canyon drainage and Mt. Lemmon highway has been closed to grazing since 1947. Small numbers of trees are cut at high elevations, but there is no systematic logging. Lightning-started fires are frequent (an average of 38 fires per year, four-fifths ignited by lightning, personal communication J. W. Waters). Fire is part of the natural environment, and probably all forest, woodland, and grassland vegetation sufficiently dense to carry fire has burned repeatedly in the past. Some more accessible canyons are occupied by camps and picnic grounds; about 300 acres of high-elevation forest are patented land in private hands for summer cabin development; and the summit meadow of Mt. Lemmon is occupied by an Air Force radar station. Access to the mountains is primarily by the Mt. Lemmon highway from Tucson to the summit, built in 1948, and the Oracle or Control road down the northwest slope, built in 1917 (Fig. 1).

Geographic relations

The Santa Catalina Mountains and the ranges north and south of them form a divide between two major landscape types. To the east is the Mexican Plateau Section with lowlands of semi-arid climate and desert grassland prevailing climax and mountains rising to oak and pine forest and the higher ranges to subalpine fir and spruce forest, the Apachean Biotic Province of Dice (1943). To the west is the Sonoran Desert Section with lowlands of arid climate on which *Cercidium-Franseria* and *Larrea* desert prevail and mountains which, west of the Baboquivari Range, are mostly low and bear Sonoran desert to their summits, the Sonoran Biotic Province of Dice. The vegetation of the Santa Catalina Mountains brings together four major community groupings of divergent geographic relations—mountain coniferous forests with northern floristic affinities, Mexican oak and pine-oak communities of southern affinities, desert grasslands with affinities to the east, and Sonoran desert with affinities to the west and south. Vegetation of the northeast slope of the Catalinas resembles that of the other ranges in the Mexican Plateau Section in Arizona in its pattern from desert grassland through woodland to forest. The southwest slope of the Catalinas is unique in having communities ranging from limited subalpine fir forests at the summit through montane fir and pine forest, pine-oak woodland and pygmy conifer oak scrub, and desert grassland to Sonoran spinose-suffrutescent desert on the lower slopes and *Cercidium-Franseria* and *Larrea* Sonoran deserts on the bajada below—the vegetational gradient which is the subject of this paper.

Methods

The orientation of the study is gradient analysis—the study of relations of populations and communities along environmental gradients (Whittaker 1951, 1956). Vegetation samples were grouped to form a grid of transects showing relations of vegetation to topographic moisture gradients in 1,000-ft (305 m) elevation belts from the summits to the base of the mountains, with an additional transect below the mountains from upper to lower bajada.

Field sampling

Vegetation samples were 0.1-ha quadrats, extending 10 m on each side of a 50-m steel tape. Trees exceeding 1 cm diameter at breast height were recorded by species and diameter. Basal diameters were recorded also for some *Arctostaphylos, Juniperus, Prosopis*, and *Cercidium*; heights

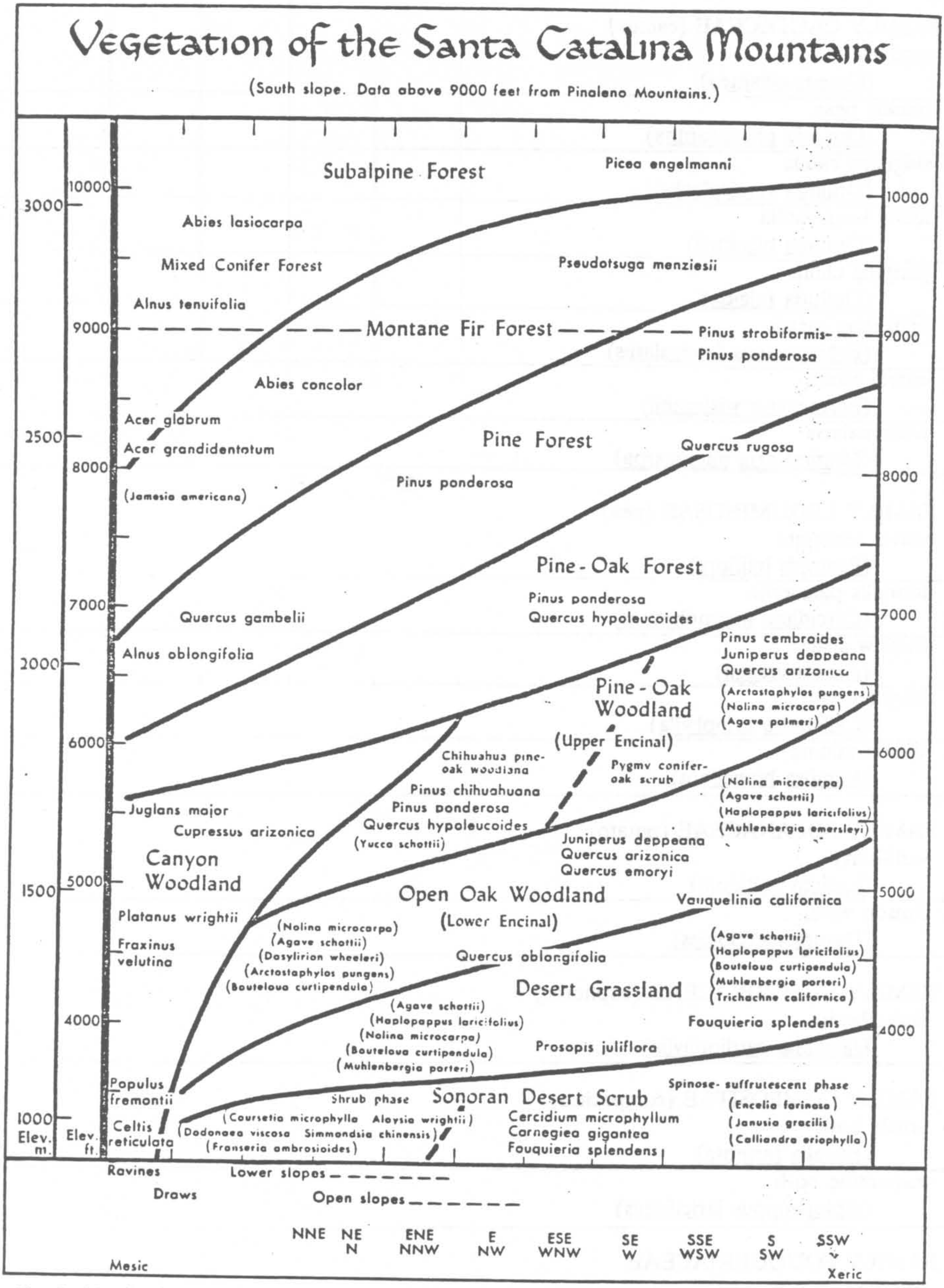

FIG. 2. Mosaic chart of the vegetation of the Santa Catalina Mountains (and elevations above 9000 ft in the Pinaleno Mts.), Arizona, based on 400 vegetation samples. Major species are indicated by their centers of maximum importance; dominants of lower strata are indicated in parentheses.

TABLE I. Summary of major plant populations in three transects in woodland zones, Santa Catalina Mts., Arizona. Densities per 0.5 hectare for trees and shrubs and percentage frequency in square-meter quadrats for herbs along topographic moisture gradients from ravines (a) to southwest-facing slopes (f), followed by percentage constancy in the 50 quadrat samples of the transect, mean coverage percentages in the transect, and (for herbs) mean densities per 0.1 hectare in the transect.

Elevation belts	V 6000-7000 ft. 1830-2140 m									VI 5000-6000 ft. 1525-1830 m									VII 4000-5000 ft. 1220-1525 m								
Species	a	b	c	d	e	f	Constancy	Coverage	Density	a	b	c	d	e	f	Constancy	Coverage	Density	a	b	c	d	e	f	Constancy	Coverage	Density
A. Trees, stems over 1cm dbh per 0.5 ha																											
Arbutus arizonica		5	23	4			32	3.0																			
Carnegiea gigantea																						9	10	35	26	.1	
Cupressus arizonica										112	205					26	7.2		119						10	3.4	
Fouquieria splendens																					7	289	402	102	52	.6	
Juniperus deppeana		3	9	31	35	32	35	2.0			10	32	30	15		60	2.9		14	27	11				36	1.4	
Pinus cembroides			9	36	113	121	34	6.0		12	84	63	55	11		74	6.4			3					4	.1	
Pinus chihuahuana			1	24	46		24	.8			4					6	.1										
Pinus ponderosa	18	280	65	2			52	10.0			29					6	2.0										
Pinus strobiformis	39	7					18	3.6			1					4	.1										
Prosopis juliflora																					2	7	18	12	32	.3	
Pseudotsuga menziesii	44	47					32	2.0		1						2	.1										
Prunus serotina ssp. virens	6	30	3				28	.9		3	5					8	.2										
Quercus arizonica		28	64	65	69	19	62	3.0		42	47	143	30	8		74	3.8		55	43	9				22	2.2	
Quercus emoryi				6	16	76	22	.8			6	44	88	41		70	1.0		23	32	33				40	1.3	
Quercus hypoleucoides	2	280	531	243	58	11	90	19.0		49	58	3				34	1.2										
Quercus oblongifolia													2	14	11	20	.2		6	27	34	5			34	2.3	
Quercus rugosa	126	76	18	14	14	11	40	2.5		64	64					26	1.0										
Vauquelinia californica													1	2	36	12	.04		6		17	25	3		18	.3	
B. Shrubs, individuals per 0.5 ha																											
Agave palmeri			66	69	87	157	50	.03		38	25	18	35	34	8	62	.04		36	30	12	5	10	5	62	.02	
Agave schottii												714	3763	5091	782	54	2.7		40	8	5133	5412	8199	7512	72	7.8	
Arctostaphylos pringlei			30	203	391	96	50	10.0			65	70	98	33		48	2.8		1	13					6	.1	
Arctostaphylos pungens			115	285	372	693	50	7.0			28	64	167	130	3	70	4.2		44	72	80				30	.9	
Artemisia ludoviciana ssp. albula	2	1			1		6				1	11	10	5	2	24	.03			3	18	32	6	2	32	.04	
Calliandra eriophylla											1	2	20	30	205	16	.11			4	19	269	711	467	50	1.0	
Crossosoma bigelovii														4	1	4	.01			1	2	14	7	2	32	.15	
Dalea pulchra														2		2					4	25	9		28	.02	
Dasylirion wheeleri			1	3	22	55	30	.16				3	28	60	94	54	.35		11	16	37	30	16	8	62	.5	
Echinocereus triglochidiatus			4	29	39	42	24	.01		4	1	2				12											
Eriogonum wrightii				2			2					9	1	30	120	26	.04			8	85	98	67	13	58	.7	
Erythrina flabelliformis													1	23	41	24	.02		10	2	12	14	5		36	.03	
Ferocactus wislizeni														3	17	18	.01				2	14	29	32	50	.03	
Garrya wrightii		3	40	46	159	50	66	2.0		13	72	182	113	118	10	88	1.9		90	136	125	1			44	1.0	

(TABLE I. Cont.)

Elevation belts	V 6000-7000 ft. 1830-2140 m									VI 5000-6000 ft. 1525-1830 m									VII 4000-5000 ft. 1220-1525 m								
Species	a	b	c	d	e	f	Constancy	Coverage	Density	a	b	c	d	e	f	Constancy	Coverage	Density	a	b	c	d	e	f	Constancy	Coverage	Density
Haplopappus laricifolius			1				2					1		358	2517	24	3.3		5	74	253	445	325	53	80	3.2	
Jatropha cardiophylla																					10	65	143	198	40	.3	
Mimosa biuncifera			2	1			6					1	5	12	6	26	.1		21	34	9	27	3		52	.24	
Nolina microcarpa		3	43	33	56	115	66	1.5		3	12	165	84	66	44	90	5.7		18	72	29	2			46	1.7	
Opuntia phaeacantha					1		2			3	3	18	5	15	15	60	.03		7	12	16	13	16	6	78	.04	
Opuntia spinosior													2	3	2	12	.01			4	4	24	42	35	56	.14	
Rhamnus californica ssp. ursina	11	101	12				28	.4		30	60					20	.4		3						2		
Rhamnus crocea var ilicifolia											1	1	1	3	13	20	.1		7	13	10	1			24	.1	
Rhus trilobata		3	2				8			15	16	29	1			26	.3		22	24	25				28	.24	
Yucca schottii	1	41	104	73	21	48	74	.5		18	137	175	93	61	6	94	1.0		41	95	46	1			42	.2	
C. Herbs, frequency percentages																											
Andropogon barbinodis													5	7	11	16	.03	54	6	7	13	10	6	1	50	.17	104
Andropogon cirratus		1	2				4	.005	10		1	20	26	19		50	.33	272		7	8	4	2		20	.11	63
Aristida orcuttiana		1	12	19	33	78	60	.86	550		1	28	32	15	14	60	.28	280	14	9	20	9	1		38	.2	167
Aristida ternipes														10	7	10	.06	44		1	2	11	34	21	36	.12	164
Bouteloua curtipendula						2	2	.005	3			7	22	44	72	56	.7	478	16	47	68	64	89	40	94	1.9	1420
Cheilanthes fendleri		13	1	1	7	6	26	.07	85		34	27	26	4	14	56	.6	388	1	20	3	2	1		26	.06	82
Cheilanthes lindheimeri			2				6	.003	9		1		2	10	23	28	.07	102	1	8	10	3		1	36	.05	62
Eragrostis intermedia										4	1	2	3	12	32	38	.08	94	6	4	7	1	4		36	.05	46
Erigeron delphinifolius		1	6	3	3	2	28	.01	39		2	7	12			24	.03	41	1	3	1				14	.01	
Euphorbia melanadenia														8	4	12	.01	18		2	9	14	8		36	.1	
Hedeoma hyssopifolium	1	10	7	2			24	.02	140		4					2	.007	40									
Lycurus phleoides						6	4	.006	6			3	4	7	10	30	.05	41	1	4	8	6	1		22	.0[illegible]	
Muhlenbergia emersleyi		22	34	32	35	40	72	1.2	497		30	78	72	44	22	81	2.2	882	11	42	18	5	2	1	66		
Muhlenbergia virescens	5	10	2	1	1		22	.08	58		2	2				8	.02	13									
Pellaea longimucronata		1		1	1	1	10	.002	5		1	1	2	4	2	22	.006	14	1	3	1	3	1		18		
Selaginella rupincola					6	12	10	.11			18	41	44	33	13	60	1.4			42	25	16	2		32		
Senecio neomexicanus		3	5	1	1		24	.007	21		3	1	1	1		12	.003	7	6	1	1				8		
Trichachne californica														2	23	14	.04	30		1	2	14	29	38	42		

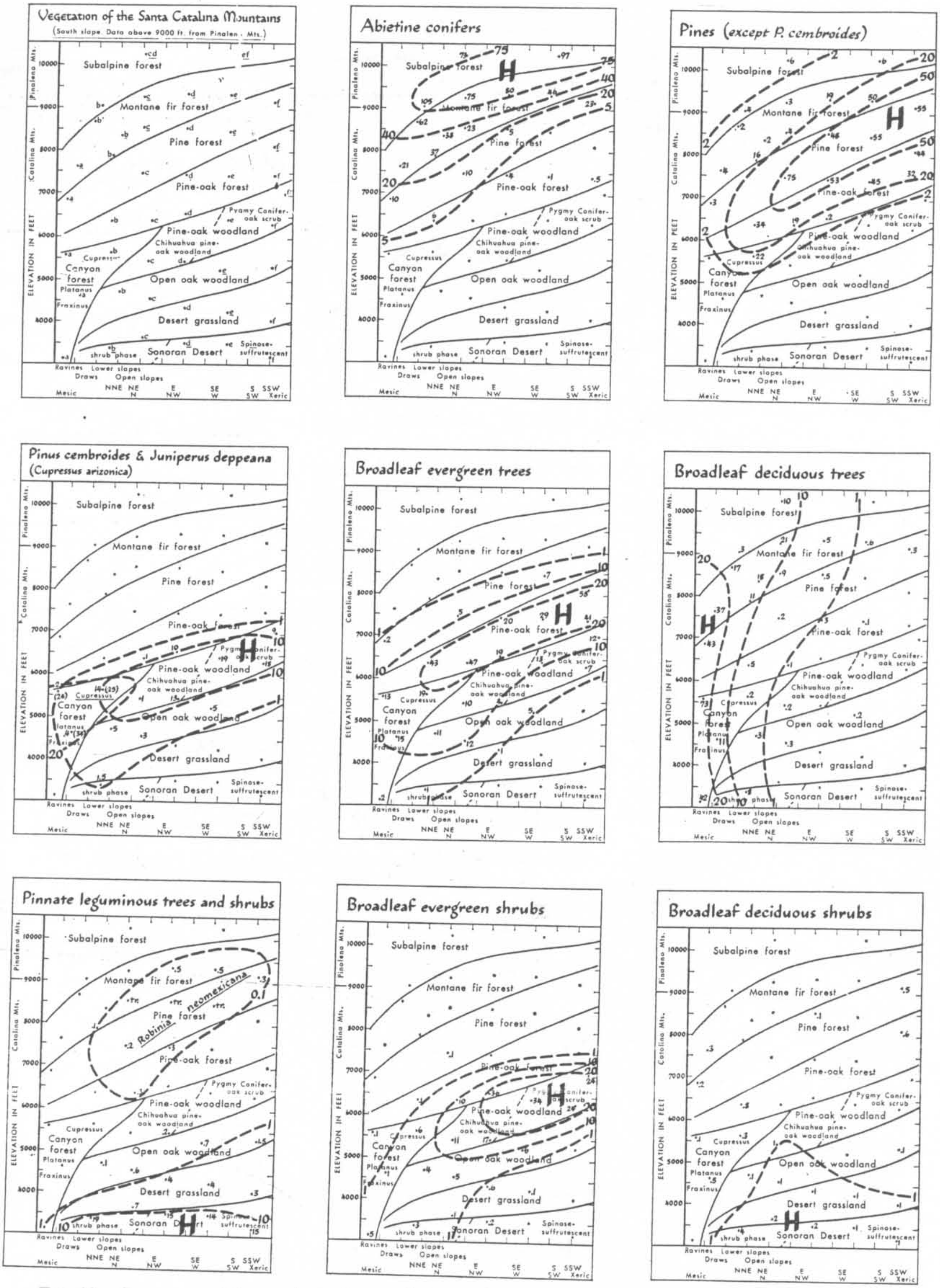

FIG. 10. Coverages of tree and shrub growth-forms in relation to the vegetation pattern, plotted for the detailed community samples in the positions indicated on the first diagram.

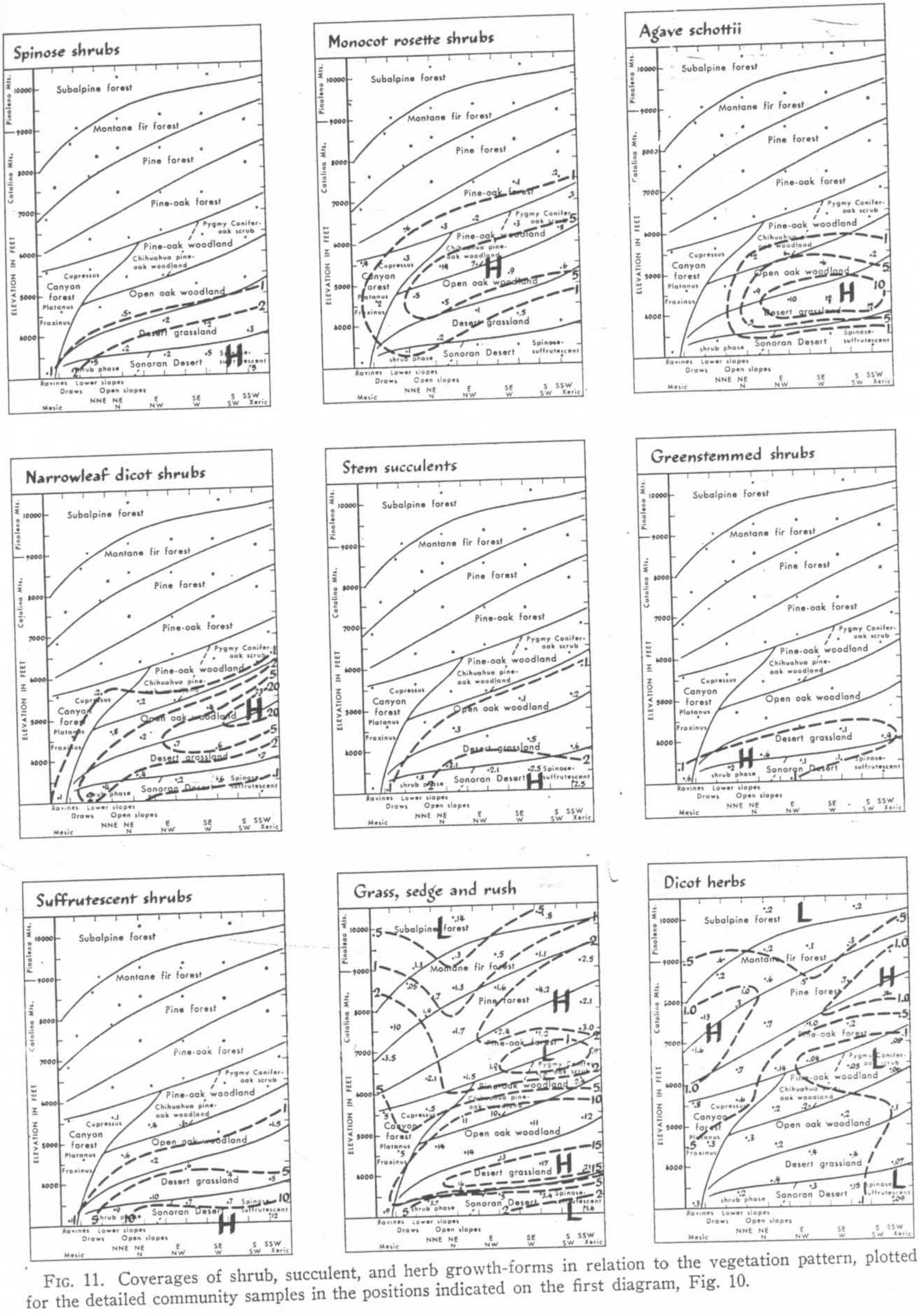

FIG. 11. Coverages of shrub, succulent, and herb growth-forms in relation to the vegetation pattern, plotted for the detailed community samples in the positions indicated on the first diagram, Fig. 10.

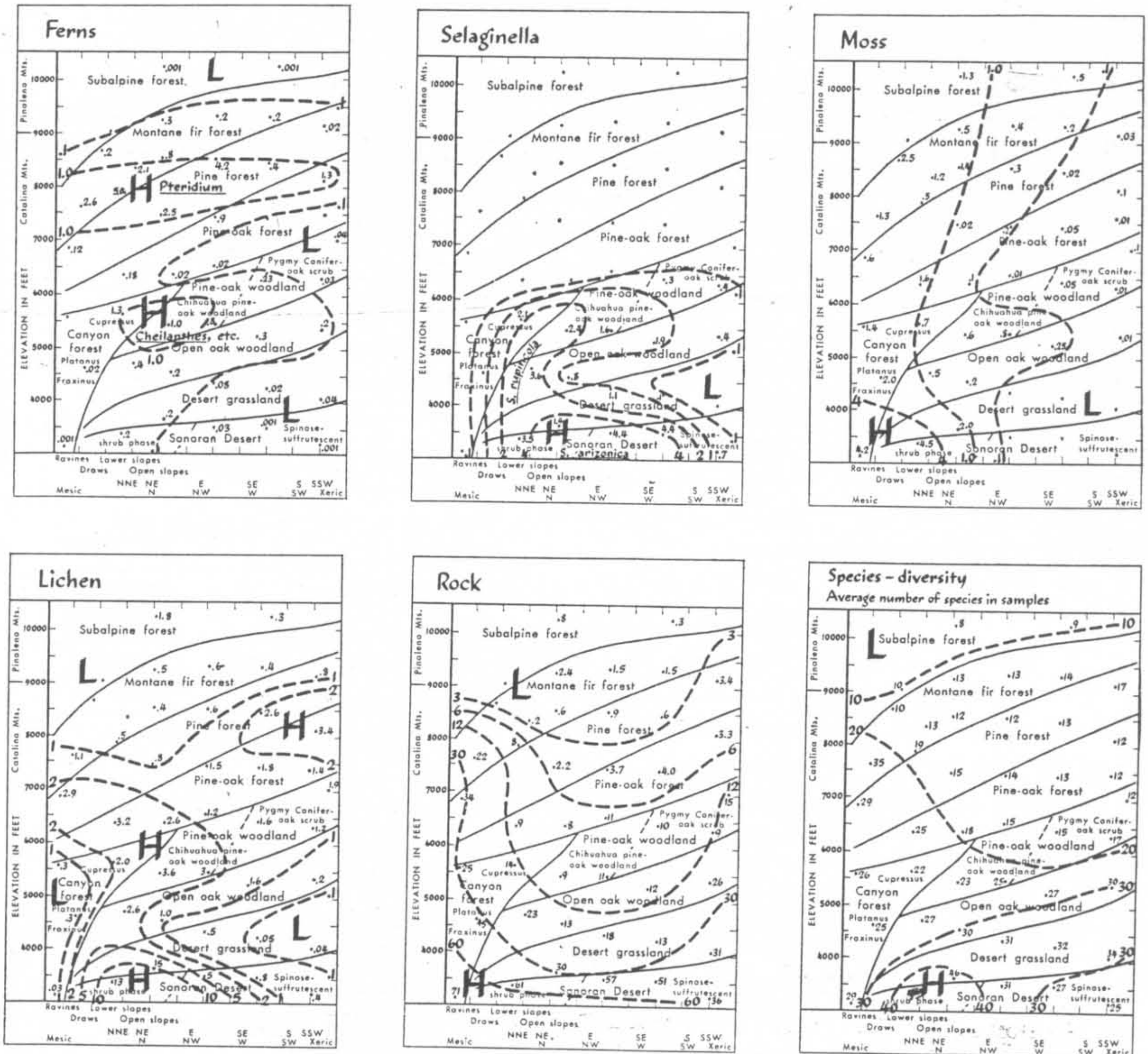

FIG. 12. Coverages of ferns, *Selaginella,* mosses, lichens, and rock, and species diversities in relation to the vegetation pattern, plotted for the detailed community samples in the positions indicated in the first diagram of Fig. 10. Coverages and species diversities in the bajada and Tucson Mountain samples are included in the complete transect tables available from the American Documentation Institute. (In the lower left portion of the diagram for Species-diversity the value given as 13 should be corrected to 43.)

cur in some more mesic desert-grassland and desert communities. Monocot rosette shrubs are (as in much of the Southwest) centered in the transition from forest into desert-grassland and less arid desert. Broadleaf deciduous shrubs are of low coverage except for *Jamesia americana* (treated as a small tree) in mesic fir forests, and *Aloysia wrightii* and other species in some stands of shrub-phase desert. Narrow-leaved dicot shrubs (*Haplopappus, Gutierrezia, Hymenoclea, Baccharis, Krameria, Selloa glutinosa, Phlox tenuifolia, Zinnia pumila, Asclepias linaria*) are centered in open oak woodlands and desert-grasslands. Some of these species, notably *Haplopappus tenuisectus* and *Gutierrezia sarothrae,* are principal grazing increasers in open woodlands, desert-grasslands, and less xeric deserts.

Green-stemmed shrubs are centered in the transition between desert-grassland and desert. The green-stemmed habit is one of the principal directions of adaptation in the desert, represented in stem-succulents, spinose shrubs (*Fouquieria splendens, Condalia lycioides*), leguminous trees (*Cercidium* spp.), and suffrutescents. The grouping used for green-stemmed shrubs (Fig. 11) is limited to *Ephedra,* in which the habit is fully developed, *Baccharis sarothroides,* and certain semi-shrubs (*Bebbia juncea, Dyssodia porophylloides, Lotus rigidus, Porophyllum gracile*). Spinose shrubs (*Fouquieria, Lycium* spp., *Condalia* spp., *Celtis pallida*) and stem-succulents (cacti) are centered in the desert of the lower mountain slopes and upper bajada. Suffrutescent semi-shrubs include more species than any other perennial

TABLE II. Floristic analysis of communities

Item	Subalpine forest	Pseudotsuga-P. strobiformis	Pine forest	Pine-oak forest	Pine-oak Woodland	Pygmy conifer-oak scrub	Open oak woodland	Desert grassland	Sonoran desert, spinose-suffrutescent	Upper bajada Cercidium-Franseria	Lower bajada Larrea	Montane fir forest	Riparian: Montane ravine forest	Riparian: Cupressus woodland	Riparian: Desert canyon woodland	Riparian: Desert wash woodland	Sonoran desert, shrub phase
Transects	I	II	III	IV	V	VI	VIe VIIc	VII	VIII	IX	IX	III	IVa Va	VIa VIIa	VIII	IX	VIII
Columns	c-f	de	de	de	cd	cd		de	de	i	l	bc			a	o	b
Elevation, feet	9700–10700	9000–9600	8000–9000	7000–8000	6000–7000	5000–6000	4500–5500	4000–5500	3000–4000	2800	2500	8000–9000	6000–8000	4000–6000	3000–4000	2700	3000–4000
meters	2950–3260	2740–2920	2440–2740	2130–2440	1830–2130	1520–1830	1400–1700	1220–1700	915–1220	850	760	2440–2740	1830–2440	1220–1830	915–1220	825	915–1220
A. Life-forms, numbers of species[1]																	
Phanerophyte	8	11	14	18	21	19	30	31	20	15	9	14	23	38	30	21	43
Chamaephyte suffrutescent				1	3	7	12	17	24	15	4		1	5	14	1	35
Chamaephyte, other	1		1	3	3	6	8	9	5	2				6	5		7
Chamaephyte-Hemicryptophyte			1	3	2	5	6	8	7	5			3	6	4	5	20
Hemicryptophyte	14	31	34	29	24	27	33	33	18	3	2	25	52	34	30.	10	43
Geophyte	2	5	5	3	2	2	3	3	3	4		7	6	4	1	1	3
Therophyte, summer				1	2	1	2	6	6	2	8	1	2	1	7.	28	13
Therophyte, winter						5	4	29	34	21	12			4	9	—	37
B. Distributional types, numbers of species[1]																	
Endemic	2	3	5	2	3	3	4	5	3			3	5	5	2		9
Southwest-Madrean	2	2	11	17	19	23	22	17	4			3	13	18	16		18
Southwest-Chihuahuan					1	1	2	5	4	6	1		1	1	4	6	7
Southwest-Sonoran						1	6	15	21	11	4			2	12	6	25
Southwestern	4	7	11	18	19	28	38	39	33	20	12	6	16	34	21	25	64
Rocky Mountain	13	11	11	9	6	2	1	1				8	12	6		1	
Western	5	13	9	6	3	3	4	2	1	1	1	10	15	6	3	4	5
Plains			1	1	1	1	4	6	2	1		1		1	1	4	2
Temperate	3	2	5	3	1		1	1	1			4	6	6	6		3
Northern	3	4	1	1								5	4	3			
Holarctic	2	4	1	1	1		1	1	1			3	7	2	2	2	1
Latin American	1	1		1	2	4	9	13	12	5	4	3	4	6	16	11	24
Introduced				1	1			1			1	1	3	3	8	7	6
C. Average geographic extents[1]																	
North	4.0	3.9	3.2	2.8	2.6	2.6	2.5	2.4	2.4	2.5	2.6	4.1	3.8	2.8	2.5	2.6	2.2
East	2.7	2.5	2.2	2.1	2.0	2.3	2.3	2.3	2.1	2.3	2.4	2.9	2.7	2.3	2.8	2.7	2.2
South	1.5	1.6	1.8	1.9	2.3	2.3	2.3	2.4	2.5	2.6	2.7	1.8	1.8	2.1	2.7	2.8	2.5
West	2.3	2.3	1.8	1.7	1.8	2.0	2.1	2.2	2.2	2.4	2.6	2.4	2.2	2.0	2.1	2.6	2.2
D. Species diversity (vascular plants)																	
In combined samples[2]	35	47	55	58	57	66	92	106	82	44	23	47	87	93	91	66	164
Per sample quadrat[3]	8.3	13.2	12.7	13.5	15.9	24.1	29.6	31.1	29.2	26.0	9.3	12.7	31.5	25.9	29.0	20.0	42.6
In combined samples[4] (including winter herbs)	35	47	55	58	57	72	98	136	117	67	35	47	87	97	100		201

[1]Species lists are based on presence in 10, 0.1-ha tree-shrub samples or 25-m² herb samples. Averages of numbers of species in the different categories in the two columns representing the community-type are used in most cases; the lists for IX-i, VIII-a, and IX-o are based on five samples only.

[2]Numbers of species (excluding winter herbs) in 10 or 5 quadrat samples, the species lists on which table sections A-C are based (except for Therophyte, winter, and Geophyte, which includes some winter species).

[3]Average numbers of species (excluding winter herbs) in 0.1 ha tree-shrub and 25 m² herb samples.

[4]Number of species in 10 or 5 quadrat samples of perennials and summer herbs, plus numbers of winter herbs collected at 1 or 2 stations representing the community type during spring collecting trips at 2-week intervals.