Flat top decay syndrome of the giant cardon cactus (*Pachycereus pringlei*): description and distribution in Baja California Sur, Mexico

Yoav Bashan, Gerardo Toledo, and Gina Holguin

Abstract: The giant columnar cardon cactus (*Pachycereus pringlei*) appears to have an ailment(s) that is destroying a large number of plants. The causal agent(s), whether biotic or abiotic, has yet to be determined. Two forms of symptom development have been recorded. The first is a circular tissue decay on a branch leading to death of the growing tip. In this case, the dead portion detaches and forms a "flat top" on the living part (hence the proposed name for this phenomenon). Progressive degeneration and death of the plant ensue. The second form is an initial circular crack on the branch without decay. Later, the green branch above the crack detaches, creating the characteristic flat top. A third type of degeneration was also observed: fatal bleaching. The time period between symptoms is unknown. It primarily affects mature, more than 100-year-old plants, but relatively young plants are also affected. Thirty-one field surveys covering the entire state of Baja California Sur found four major and three smaller centers of flat top decay. We believe that flat top decay syndrome of the cardon cacti in Baja California is common and widespread.

Key words: cactus decay, cactus deformation, cactus diseases, columnar cacti, *Pachycereus*, phytopathology.

Résumé : Le cactus columnaire géant *(Pachycereus pringlei)* semble frappé d'une affection(s) qui détruit un grand nombre de plantes. L'agent(s) causal(s), biologique ou non, n'a encore jamais été déterminé. Les auteurs ont observé le développement de deux formes de symptômes. Le premier se manifeste sous forme de caries circulaires des tis sus au niveau d'une branche, conduisant à la mort de 1'apex en croissance. Part la suite, la partie morte se détache et forme un sommet aplati sur les autres parties vivantes (d'où le nom proposé pour ce phénomène). Il s'ensuit une dégénération progressive conduisant à la mort. La seconde forme débute par une fente sur la branche, sans qu'une carie se développe. Plus tard, la branche verte au dessus de la fente se détache, conduisant encore une fois au sommet aplati caractéristique. Un troisième type de dégénérescence a également été observé : la décoloration fatale. La durée entre les symptômes demeure inconnue. Cette dernière forme affecte surtout les plantes adultes agées plus d'une centaine d'années, mais les plantes relativement jeunes ne sont pas affectées. Un ensemble de 31 relevés effectués sur le terrain, couvrant la totalité de 1'état Baja California Sur montre quatre foyers majeurs et trois foyers plus petits où se manifeste le carie avec sommet aplati. Chez cc cactus, les auteurs croient que le syndrôme de la carie avec sommet aplati est commun et général dans la région de Baja California.

Mots clés : carie des cactus, déformation des cactus, maladie des cactus, cactus columnaire, *Pachycereus*, phytopathologie.
[Traduit par la redaction]

Introduction

The giant columnar cardon cactus is the emblem and principal landmark of the Baja California peninsula, being the most massive plant growing in its deserts. These tree cacti can reach heights of up to 20 m and weigh over 25 000 kg (13, 20). The cactus is an extremely slow grower, exhibiting only a few centimetres of growth per year, and probably has a life-span of hundreds of years.

This longevity may infer that the cardon is virtually resistant to most lethal plant pathogens and pests. Although mature plants produce an abundance of viable seeds, seedling establishment is extremely poor, since most seedlings are consumed by rodents during the long dry season when all perennial plants are leafless and the annuals are dry (13). After the initial year, survivors may protect themselves against further predation by producing various toxic compounds such as alkaloids (13, 16).

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Table 1. Evaluation sites for decay of cardon populations in the state of Baja California Sur, Mexico.

Location	Geographical location		Point of entry to the site
	Lat. N	Long. W	
Sierra de la Laguna	23°23'	109°51'	The entrance to the site is a dirt road starting from Mexico Hwy. 1 at the southern side of the agricultural village of San Bartolo
San Juan de los Planes	23°50'-24°00'	109°53'-110°00'	Entrance to the site is from the paved road entering the village of San Juan de los Planes from La Paz; there is a right turn into a dirt road before the first permanent house of the village
CIB preserve, La Paz	24°08'	110°26'	Located around the Center for Biological Research, 17 km northwest of La Paz on a paved road connected to Mexico Hwy. 1; the site is along the southern fence of the center
Cerralvo Island	24°10'-24°22'	109°48'-109°57'	By boat from the fishing village of El Sargento
Pichilingue hills	24°16'	110°19'	The hills above Pichilingue port (La Paz port), 22 km north of La Paz on paved road
Balandra lagoon	24°19'	110°19'	Entrance to the site was on the La Paz - Balandra bay beach road, 25 km north of La Paz and 3 km before Balandra lagoon on the right-hand side of the road
Espiritu Santo-Partida Island	24°23'-24°36'	110°16'-110°26'	By boat, located about 30 km north of La Paz
El Conejo	23°21'-24°11'	110°58'-111°00'	The entrance to the site is a dirt road at km 80.5 of Mexico Hwy. 1 north of La Paz, about 2-3 km south of El Coyote microwave tower (the dominant landmark in this flat land); the general direction of the road is southwest; the injury in this area was located around 2-22 km from the junction with the highway; this decayed area extended up to 2 km from the Pacific Ocean shore
Mesa Prieta	24°29'-25°01'	110°47'-111°20'	The entrance to the site is from a northeasterly dirt road at km 127.5 from Mexico Hwy. 1 north of La Paz; when the road enters the Sierra 42 km from the junction (Las Tinajitas area), a center of decay begins and was present until km 52
North of Loreto	26°05'	111°22'-111°27'	The entrance is west bound on a dirt road from Mexico Hwy. 1, 8.5 km north of Loreto into the large wash bed; it is 1 km before the microwave tower of Loreto
Southern Bahía Concepcíon	26°33'-26°40'	111°41'-111°45'	Entrance to this site was at a small dirt road 75.3 km north of Loreto on Mexico Hwy. 1; the site was observed from km 0.5 of the dirt road (from the highway) until km 8 before the dirt road turned north to the eastern beaches of Bahía Concepcíon
Volcano Las Tres Virgenes	27°24'-27°31'	112°30'-112°32'	The entrance was at a dirt road 32 km west of the town of Santa Rosalfa on Mexico Hwy. 1 on the eastern slopes of the volcano; the only decaying zone in this area was detected between 6.5 and 9 km from the entrance, with the strongest decay between 6 and 7 km
Eastern slopes of Sierra San Francisco	27°26'	112°48'	The entrance to the site was at a dirt road 53 km north of Santa Rosalfa on Mexico Hwy. 1 through the village Alfredo Bonfil, the center was observed between 13 and 14 km from Alfredo Bonfil

NOTE: Site locations are listed from south to north.

The destruction of a desert "forest" will probably take hundreds of years for natural reforestation (L. Jackson, personal communication). Areas in the state of Baja California Sur which were deforested 30-40 years ago are still completely barren and lack any signs of natural reforestation (J.L. de la Luz, personal communication). This is probably because the most common nurse plant (11), the mesquite, was cut for firewood (17). Despite local, "popular" knowledge about cardon properties as a traditional medicinal plant, almost nothing has been published on this cactus in scientific literature (12, 21, 23).

Recently, a degeneration of the cardon population was

detected in a wilderness area near the city of La Paz in the state of Baja California Sur, Mexico. Mature plants died in large quantities without apparent reason (14). Attempts to isolate pathogenic organisms and to perform Koch's postulates failed, although numerous microorganisms were isolated (Y. Bashan, L. Alcaraz-Melendez, and M.A. Guzman, unpublished data). The aims of this field study were to describe the visible symptoms of this syndrome and to determine its geographic magnitude.

Materials and methods

Thirty-one field surveys were conducted during 16 trips in a four wheel drive truck and on foot during springs and winters of 1993 and 1994 (the only possible time for intensive fieldwork in Baja California Sur). The surveys covered virtually the entire state of Baja California Sur from the Vizcaíno Desert in the north (28°N) to Cabo San Lucas at the southern tip of the peninsula (23°N). All cardon habitats were covered, including two islands in the Gulf of California (Espiritu Santo-Partida and Cerralvo). Large parts of the peninsula are virgin wilderness lacking paved roads; therefore, the surveys were restricted to dirt roads, or to rancher's trails as long as they could be negotiated with a rugged off-road vehicle. While conducting surveys on foot, some terrain was inaccessible due to dense "forests" with low canopy, and thorny, bushy plants. A grid survey technique was impossible because of the large area to be surveyed (the entire state) and the inaccessibility of most terrain to ground motor vehicles.

Since symptom severity differed from plant to plant (from initial rot spots to plant death), the following random survey method was adopted. A total of 13 sites were evaluated in detail (Table 1). Once a decayed site was located, we created five ad-hoc evaluating stations as follows. After arriving at a potential decaying site, we roughly surveyed its boundaries and estimated the intervals at which evaluating stations could be placed. Usually station 1 was placed in the approximate center of each site and the other four stations at constant distances. At one site (the island Espiritu Santo-Partida) the rough terrain permitted the placement of only three stations. The distance between stations in each location was constant but differed between the locations (ranging between 200 and 1000 m, depending on the natural size of each decay site). At each station, a circular section of terrain having a diameter of 100 m, we counted the total number of cardon plants and the number of plants exhibiting "symptoms," regardless of severity. Surveys were also conducted in 18 areas in addition to the ones described in Table 1. In these areas, the injuries were light (< 5 % decay) or nonexistent, thus no attempt was made to evaluate these areas in detail. Individual plants were evaluated by observing decay symptoms (described later). A plant was considered "diseased" regardless of symptom severity. The percentage of cardon decay in a site was calculated by dividing the number of cardon plants showing any injury (in all the stations of a particular site) by the total number of plants in this site. The data from all the locations in the state were then analyzed using one-way analysis of variance (ANOVA) at $P \leq 0.05$.

This survey used the latest available maps of Baja California Sur, made and printed in 1993 by Instituto Nacional de Estadística, Geografía a Informática (INEGI). All kilometre markings in this study were according to the official, actual road signs on Mexico highway 1. Distances on dirt roads were taken by reading the survey car's odometer. Both measurements may vary. Imposed by these limitations, we gave the geographical coordinates of each location as supportive data to assist readers and future travelers to these sites. In sum, this study included 48 km of foot survey and 1442 km of car survey. We evaluated a total of 3883 plants of which 1405 were suffering decay.

Results

Description of flat top decay syndrome

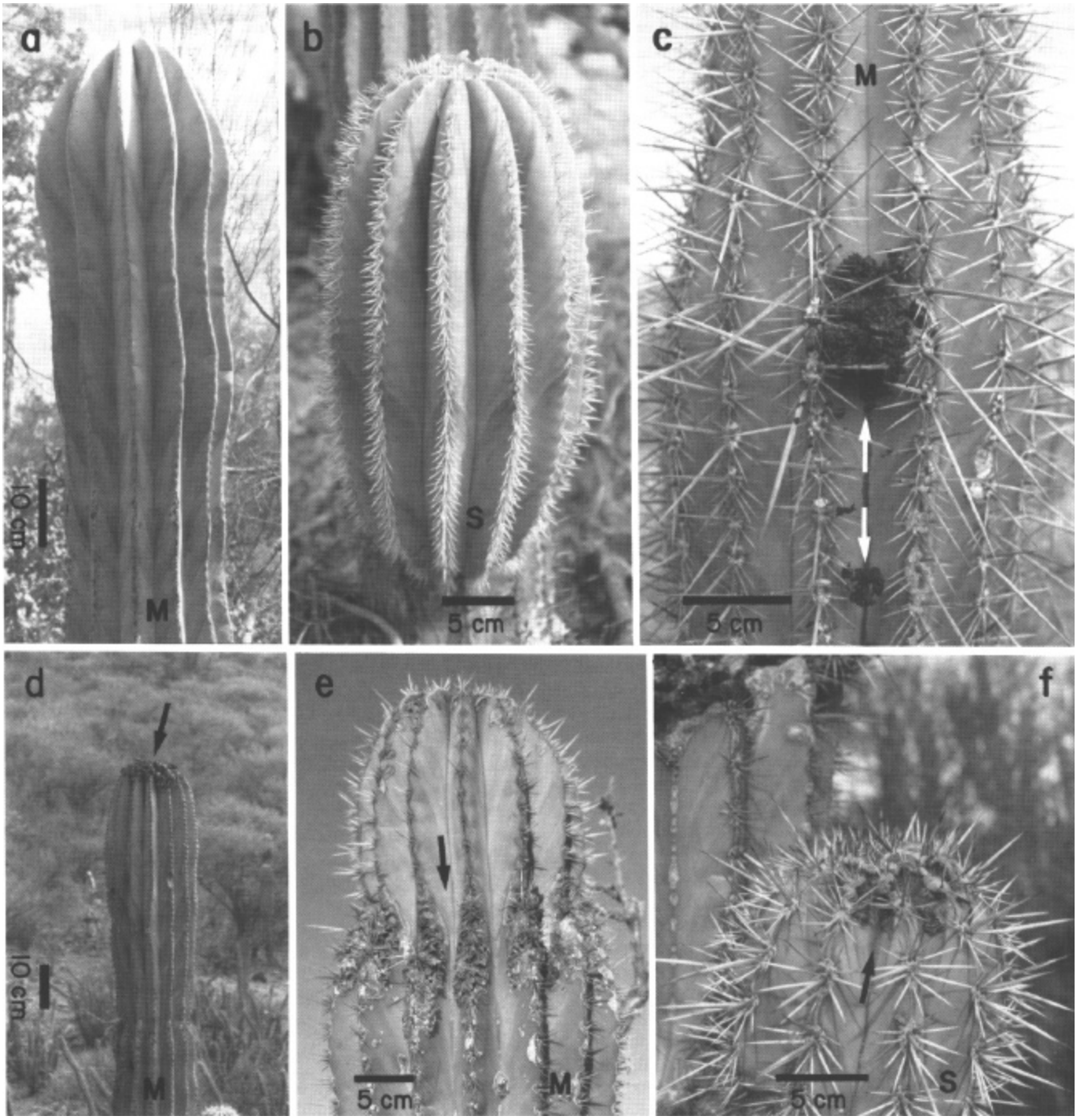
Cardon (*Pachycereus pringlei*) populations, which populate deserts and low hills of all southern Baja California, in "infected areas" showed various degrees of decay. By closely evaluating more than a 1000 infected young and mature plants, it was possible to reconstruct a possible pattern of decay. Primarily, the tissue surrounding the plant branch or top starts to rot (an area no bigger than 2-3 cm width). The rot creates a full circle around the branch (in a mature plant) or the main stem (in a younger plant) (Fig. 1). Then, the top itself starts to rot. After an unknown period of time, the rotting area dries. Later, the dried top detaches, creating a new flat top on the still-living part (Figs. 2 and 3). This pattern inspired the name we proposed for this phenomenon: flat top decay syndrome of cardon. Heavy infection of flat top decay could create a plant that looks as if all its branches were chopped off. Later, more branches degenerate in the same manner, and the plant gradually deteriorates and dies. After tissues dry, the soft wood of the cardon disintegrates and the plant completely disappears (data not shown). This type of decay was found mainly (but not exclusively) in the area between the city of La Paz and the town of Cuidad Constitucion (locations are described in Table 1).

In an alternative pattern to this "ailment", the primary decay is very limited and occurs only in a singular, circular deep crack on a branch. The crack is 1-2 cm wide, but its depth inside the tissue can reach up to 10 cm. In cases where the crack occurs in a mature, heavily branched plant, the entire branch (including green, nonaffected areas) collapses and falls to the ground, creating the image of an amputated finger (Fig. 4). The next stage is the death of still-attached branches. Later, the entire giant plant dies and in many cases falls down. Living parts of the collapsed plant cannot reroot themselves, and eventually the giant plant dies. This sort of decay was found exclusively in the area south of Bahía Concepción (location is described in Table 1).

Gray decay of cardon

Although flat top decay is the more common phenomenon detected, another degenerating manifestation was observed on the Pacific coast 4-5 km south of the fishing camp of El Conejo (for location see Table 1). In this particular location, the entire mature population (which is generally green elsewhere) turns gray or even white, and the plant epidermis cracks. Many of the plants in this area are dying from this ailment (data not shown). This phenomenon is restricted to a 3-km^2 area and was not further studied.

Fig. 1. Initial symptoms of decay. *M*, main stem; *S*, side branch. (*a*) Healthy cardon in an unnamed wash north of Loreto. (*b*) Close-up of a healthy side branch. Note the perfect shape of cardons at this site. (*c*) Small rotting spots (arrows) anywhere in the main stem of mature cardon. (*d*) Rotting in the top of the main stem (arrow). (*e*) Circular rotting of main stem top (arrow). (*f*) Rotting of the top of a side branch (arrow). Location of the photographed cardons as they appear in Fig. 5. *a* and *b*, 26°05' N and 111°22'-111°27' W; *c* and *e*, site 2; *d* and *f*, site 3.

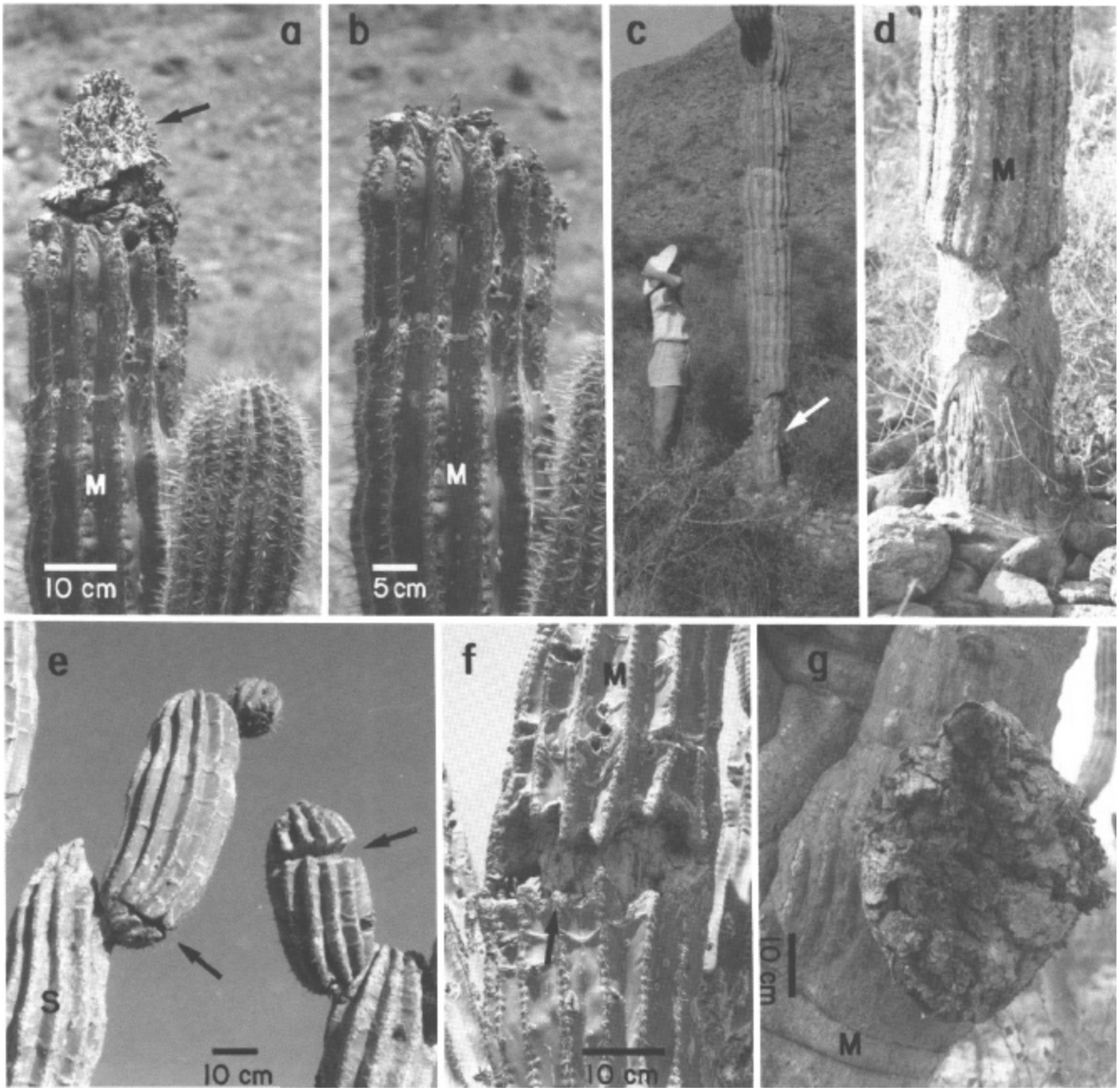


Decaying sites and the level of decay

Field surveys located four large, highly infected areas and three smaller sites. The first of the four large areas was the island of Espiritu Santo-Partida, the second site was in Mesa Prieta, the third was the El Conejo area, and the fourth was southern Bahía Concepcíon. The smaller decay areas were southern Balandra lagoon, volcano Las Tres Virgenes area, and the eastern slopes of Sierra San Francisco (for location and points of entry see Table 1).

The number of decaying cardons varied from site to site, being highest at El Conejo and on the island of Espiritu Santo-Partida, and lowest at an unnamed wash north of

Fig. 2. Advanced symptoms of decay. *M*, main stem; *S*, side branch. *(a)* Drying of the main stem top (arrow). (*b*) Close-up of Fig. 2*a* after the dry top was easily detached by touching. (*c*) Circular rotting, and detachment of the entire base tissue (arrow). (*d*) Close-up of Fig. 2*c*. (*e*) Dry cracks in almost every branch of the plant (arrows). (*f*) Dry deep crack in the main stem of a plant (arrow). (*g*) Large dry rotting of a side branch. Location of the photographed cardons as they appear in Fig. 5. *a-d* and *f*, site 1; a and g, site *2*.



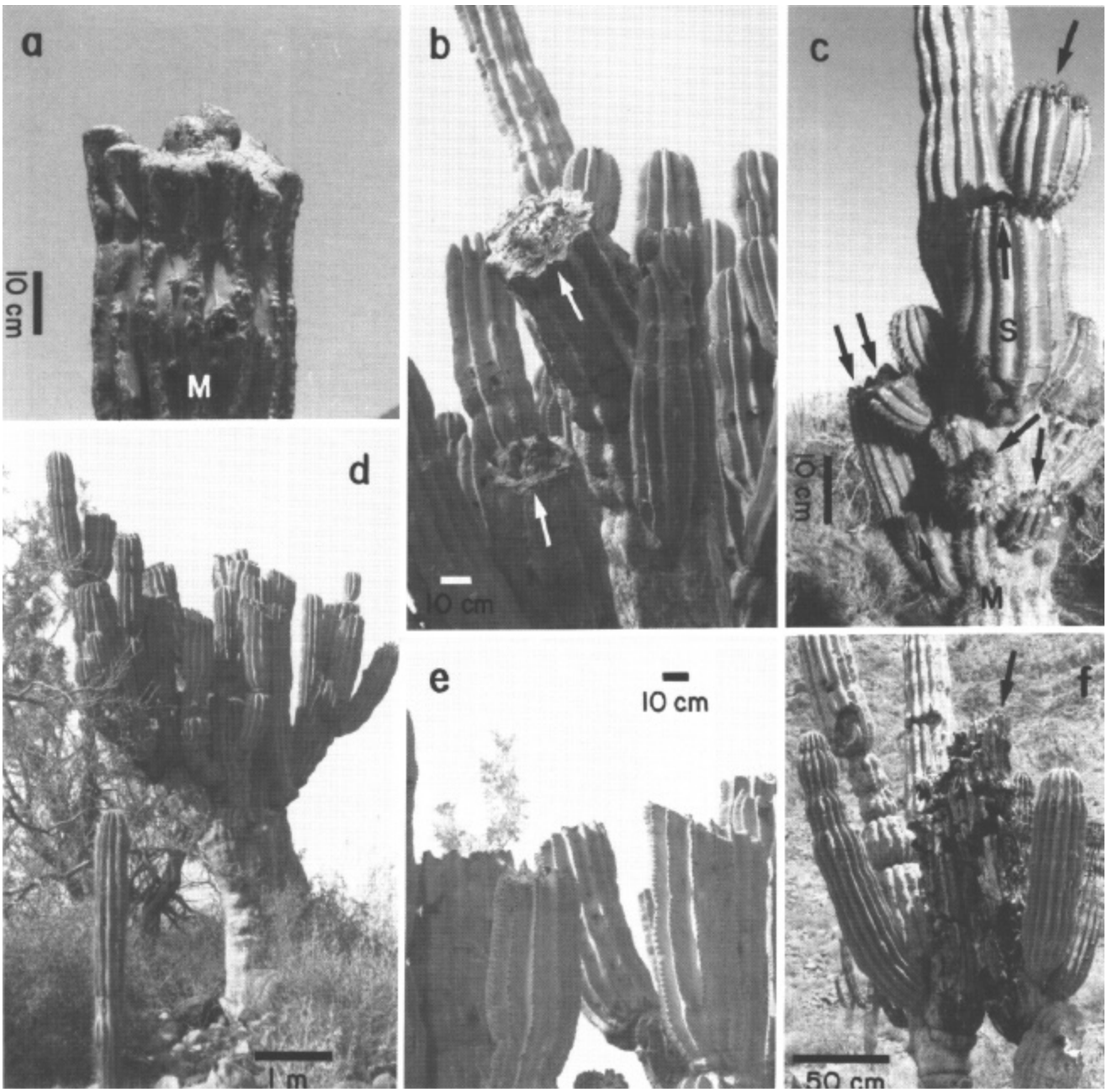
Loreto and in the southern part of the peninsula at Sierra de la Laguna. In the latter two sites all the plants were unaffected (Table 2).

Discussion

Degeneration, decay, or destruction of mature plant populations, especially ones that reproduce very slowly, is a clear indication of some major change that the old plants could no longer tolerate. Such is the case in the decay of cardon populations of *P. pringlei*, the largest plant in Baja California. Only mature plants (a few metres tall and approx. 50-100 years old) flower and produce seeds. However, seedling establishment is poor. For the cardon, a falling branch cannot reroot as is common for some other cacti (13). This further emphasizes the extreme importance of old-growth cardon in sustaining its population.

We first discovered a small decaying area almost 4 years ago 25 km north of La Paz (14). While alive, the cardon is

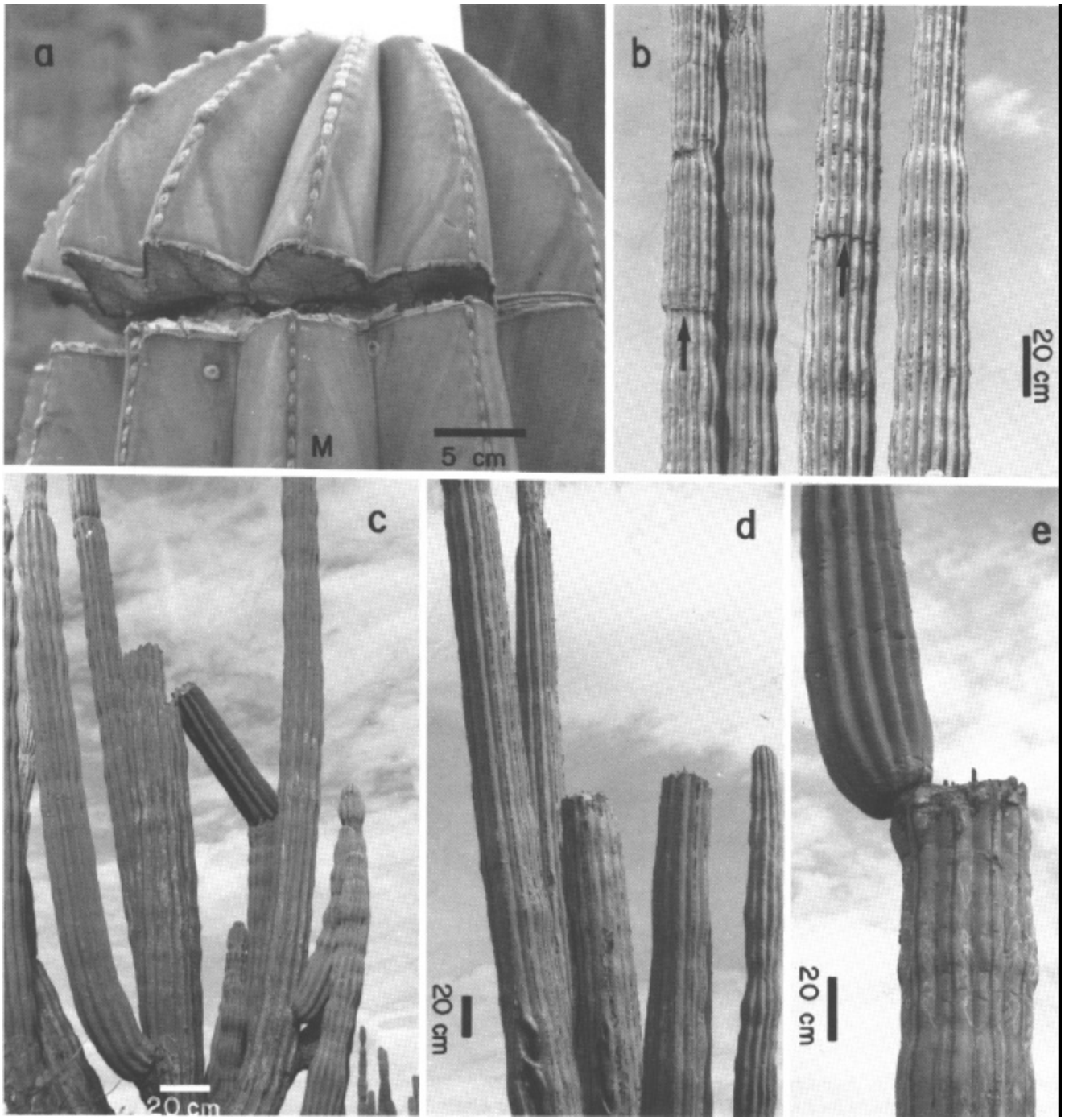
Fig. 3. Typical symptoms of flat top decay of cardon. M, main stem; S, side branch. (*a*) A typical flat-top symptom of a main stem. (*b*) Large flat tops of major branches (arrows). (*c*) A cardon suffering a continuous decay in each branch (arrows), forming a strange shape. (*d*) A large cardon exhibiting flat tops in almost all of its branches. (*e*) A close-up view of *d*. (*f*) Death of the main branches (arrow). Location of the photographed cardons as they appear in Fig. 5: *a* and *f*, site 1; *b-e*, site 2; *c*, site 3.



one of the most massive of all cacti (13, 22), but like many other cacti, it contains mostly liquids and a relatively small quantity of soft woody tissue. Shortly after its death the plant deteriorates. In highly infected areas, it is virtually impossible to assess the previous plant population, since almost nothing remains. Such is the case of our original discovery at Balandra lagoon (14). Today, most of the dead cacti photographed 4 years ago at that site have completely disappeared. We named this phenomenon flat top decay syndrome of cardon, since this term describes the most common visible symptom. We add the word syndrome because it is not yet known whether the different decaying phenomena detected in this study are caused by a single or by several agents.

Our basic strategy was to evaluate the magnitude of the phenomena by field surveys of the entire state of Baja California Sur. Two cardon species thrive in southern Baja California, *Pachycereus pectan* and *P. pringlei* (22). Apparently *P. pectan* is resistant to whatever causes this decay. In places where the two cardon populations overlap, only *P. pringlei* plants are affected.

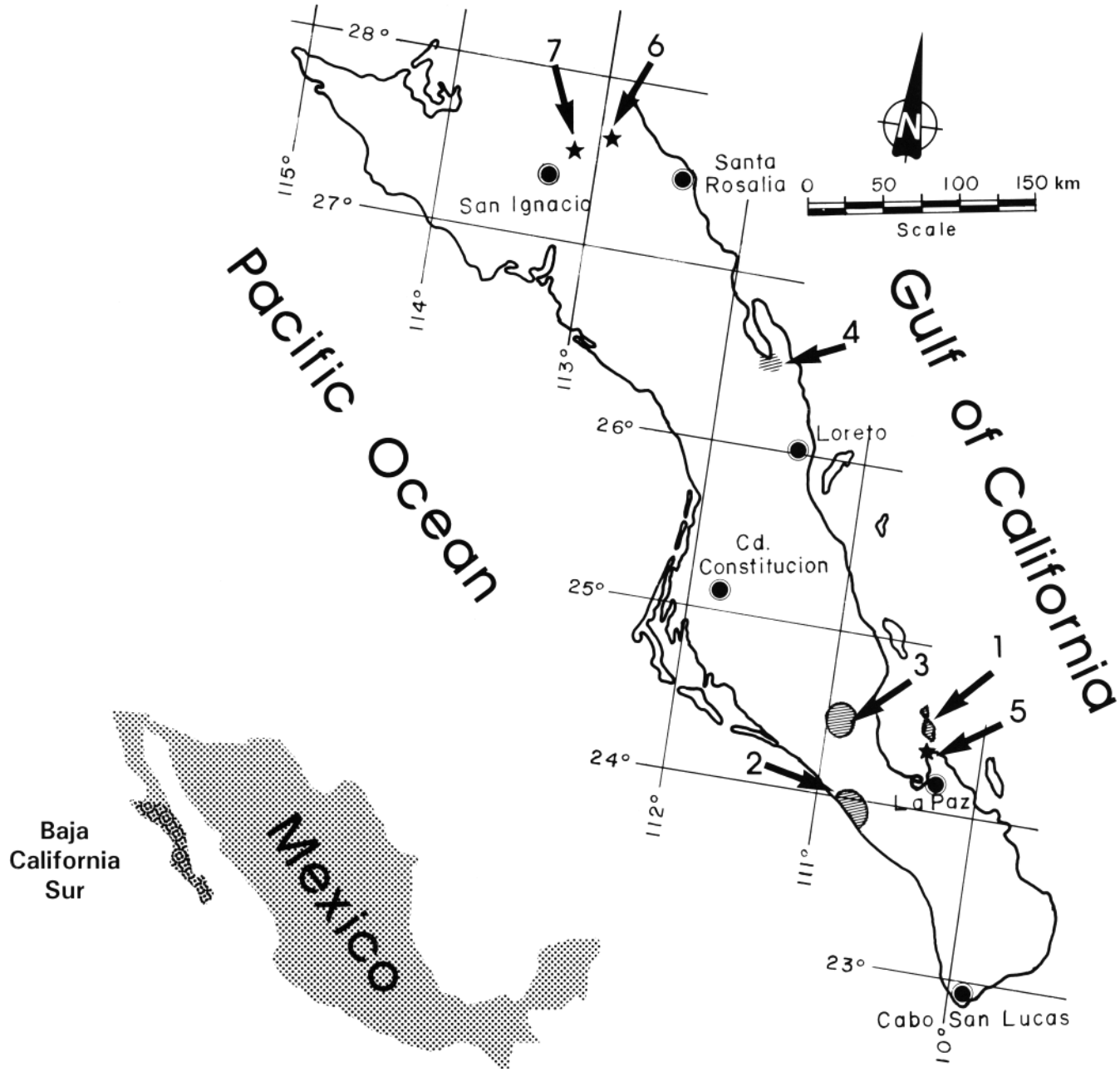
Fig. 4. A second pattern of flat top decay found only in the southern Bahía Concepcíon area (site 4 in Fig. 5). *M*, main stem. (*a*) The decay starts with a single deep crack in the main stem of the plant without apparent additional rotting. (*b*) Deep cracks may appear anywhere along the branches (arrows). (*c*) When the crack is deep enough, the branch falls. (*d*) Common flat top decay of cardon in Bahfa Concepcfon. (*e*) A flat top branch may grow a side branch that can reach more than 5 m.



Not all *P. pringlei* plants are evenly decayed. It appears that the affliction is localized in small restricted areas (Balandra lagoon area, volcano Las Tres Virgenes area, and the eastern slopes of Sierra San Francisco) or much larger zones (probably more than 100 km^2 in the area of El Conejo and Mesa Prieta, for example) while completely absent from the other zones. Affected and nonaffected zones can be geographically close, as in the relatively healthy Pichilingue hills area, which is only 4 km south of the highly afflicted Balandra lagoon.

Of the two islands in the Gulf of California that were surveyed, one (Isla Cerralvo) is virtually unaffected. The other island (Isla Espiritu Santo-Partida), which lies just 30 km to the north, but only 5 km from the original decay site in

Fig. 5. Location of major (patterned areas) and minor sites (★) with decay of cardon populations in the state of Baja California Sur, Mexico. 1, Isla Espiritu Santo-Partida; 2, El Conejo; 3, Mesa Prieta; 4, Bahía Concepcíon; 5, Balandra Lagoon; 6, volcano Las Tres Virgenes; 7, eastern Sierra San Francisco.



Balandra lagoon, is heavily degenerated with dead and decaying plants. The geographical location of the two islands and the prevailing wind patterns point to the involvement of a pathogenic organism(s).

Wind alone cannot explain the location of the most severe infliction detected so far in the wilderness between La Paz and Cuidad Constitucion. There, two large infected areas were detected, namely Mesa Prieta and El Conejo, where the vast majority of plants were inflicted, although the number of dead cacti was small. Possible explanations are (*i*) the dead ones completely disintegrated as explained above; (*ii*) when the plants fell, they became obscured, like telephone poles lying on the ground, and thus it was difficult to detect them among the dense, thorny bushes that covered the entire area; and (*iii*) the degeneration in these areas does not kill the plants but only a part of a branch, leaving a living part to grow a new, partially affected branch, thus the circle goes on producing strange-shaped cardon. This type of degeneration was widely observed in these areas.

Degeneration of the cardon cactus is not an isolated case

Table 2. The extent of decay in cardon populations in Baja California Sur, Mexico.

Location	No. of field stations	Distance of survey (km) *	No. of cardons sampled	No. of cacti with injuries in the site	% decay†
Sierra de la Laguna	5	25 (C); 3 (F)	83	0	0*a*
San Juan de los Planes	5	12 (C); 2 (F)	211	6	2.8*a*
CIB preserve, La Paz	5	4 (F)	213	10	4.6*a*
Isla Cerralvo	5	11 (F)	417	3	0.7*a*
Pichilingue hills	5	3 (F)	226	16	7*a*
Balandra lagoon	5	4 (F)	394	91	24*b*
Isla Espiritu Santo-Partida	3	5 (F)	261	237	90.8*d*
El Conejo	5	51 (C); 2 (F)	671	663	98.8*d*
Mesa Prieta	5	175 (C); 1 (F)	255	158	61.9*c*
North of Loreto	5	9 (C); 2 (F)	500	0	0*a*
Southern Bahfa Concepcion	5	28 (C); 2 (F)	239	77	32.2*bc*
Volcano Las Tres Virgenes	5	18 (C); 1 (F)	188	62	32.9*c*
Sierra San Francisco	5	42 (C); 8 (F)	225	82	36.4*c*
18 additional areas‡	nd	1084 (C)	nd	nd	nd
Total	63	1142 (C); 48 (F)	3883	1405	

*, C, car survey; F, foot survey.
†Numbers followed by different letters in this column differ significantly at $P \leq 0.05$ in one-way ANOVA.
‡Lightly infected (< 5 % decay) or noninfected areas visited during this survey. nd, not determined.

among columnar cacti. Giant specimens of the saguaro (*Carnegiea gigantea*) in Arizona have almost disappeared in the last decades. Most plants that currently grow in the Saguaro National Monument in Arizona are relatively young (17). In Chile, extensive populations of the huge eulychnias cacti have died in extremely remote areas and probably without any direct human interference (5). Recently, four long-lived columnar cacti of the Sonoran Desert in Mexico were reported as having epidermal browning (6).

The reason(s) why the giant cacti are dying is unknown. In the case of the saguaro, the explanations have varied between a depletion of the ozone layer, subjecting the plants to excessive exposure to ultraviolet irradiation, copper-smelting pollution, car pollution, freezing temperatures, bacterial necrosis, and long-term precipitation patterns (15, 20). However, it should be emphasized that there is not suffi-cient scientific evidence for any of the proposed theories. Apparently, none of the above reasons are valid for the cardon decay. The degenerated populations were found in extremely remote, barely accessible areas, far from any human activity. In the cardon habitats, there is no industry or intensive modern agriculture for hundreds of kilometres around, ruling out man-made pollution.

From the data collected so far, we cannot conclude that this is a new phenomenon. On one hand, Baja California is a well-toured area (apart from its remote zones), yet no previous report exists on the decay of cardon population, a phenomenon easily observed by the untrained eye. On the other hand, plants that have some branches definitely harboring flat top syndrome recovered and grew large side branches (up to 10 m tall) from the side of the flat top, indicating that the original flattop occurred dozens of years ago.

The rotting tissues of the cardon provide a habitat for large numbers of microorganisms; undoubtedly the vast majority are saprophytes. The phenomenon of "jungle type" bacterial communities within the rotting tissue of cacti is not unique to cardon. Analyses of bacterial communities in three other necrotic columnar cacti's tissues revealed numerous different isolates belonging to 28 bacterial groups, yet none of the bacteria were apparently related to the primary cause of the necrosis itself (7, 9, 10). Yeast communities have been associated with the decaying of cactus, but only as secondary colonizers (8).

There is no scientific evidence for the involvement of pathogenic agents in any of these degenerations. Furthermore, reports on cacti pests and pathogens in nature are rare (1, 3, 4, 18), except for biological control of *Opuntia* species from various insects (19, 24). Therefore, one has to assume that, in their natural habitat, cacti have a tolerance to pathogenic agents. For example, the cardon cactus has an effective peroxidase that may protect it against invasion from harmful microorganisms (12). However, since the cardon may live hundreds of healthy years without any infliction, this might be a new pathogen or an opportunistic microorganism turned pathogenic by a spontaneous mutation. Furthermore, the appearance of the infliction in restricted areas resembles the spread of a pathogenic agent from a small center. This type of phenomenon is well documented for many bacterial and fungal pathogens (2). However, as long as Koch's postulates have not yet been demonstrated, all of these are just theories. In conclusion, we propose that this decaying phenomena of cardon cacti in Baja California is common and widespread.

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