# The Probable Geographic Distribution of *Coccidioides immitis* in Mexico*

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## Introduction

A variety of studies made in the United States have given clues as to the probable geographic distribution of *Coccidioides immitis*. Epidemiologic studies have tended to confirm the biogeographical studies in particular. Application of this information to weather data available from Mexico (1) provides clues to the geographic distribution of this fungus in Mexico.

## The Lower Sonoran Life Zone

Merriam (2) classified the United States into several biologic life zones, one of which is the Lower Sonoran Life Zone. Since that time there have been numerous modifications and refinements of the life-zone concept. These zones were first divided according to the sums of the degrees of temperature above a given degree for a year, added to the mean temperature for the warmest 6 weeks. This classification was based on the knowledge that plants grow only when the environmental temperature is above a certain point. These zones were subdivided into their humid and arid provinces, and the plant and animal life was studied as to its distribution within the zones. These life zones are useful as broad geographic areas in aiding general ecologic studies of plant and animal life. Hall and Grinnell (3) have pointed out that for analyzing the ecology of the area of smaller geographic subdivisions, a study of plant and animal associations is more useful. Slope exposure, air currents, streams carrying cold water, evaporation from moist soil, proximity to large bodies of water, influence of lingering snow banks and of glaciers, changes in vegetative covering, extent of a mountainous area, rock surfaces, and other miscellaneous local influences can alter the characteristics of a life zone in a local area.

The life-zone concept is empirical, and biologists do not agree on the number of zones or the divisions. For example, there is a question about the exclusion of the Edwards Plateau in Texas as well as parts of northwest Texas and southwest Oklahoma from the eastern end of the lower Sonoran Life Zone. Biologists also do not agree as to the value of the life-zone concept in the study of plant and animal life; some prefer to use a biotic province concept for these studies.

The Lower Sonoran Life Zone is characterized by arid and semi-arid climates, with hot summers and few winter freezes, low altitude, and alkaline soil. Only certain types of plants and animals can survive in this environment. Only this environment seems to permit *C. immitis* to exist in nature as a soil organism (Figs. 1–4).

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FIGURE 1 — Stained smear of mycelial phase of *Coccidioides immitis* showing arthrospores formed within the mycelia. × 970.

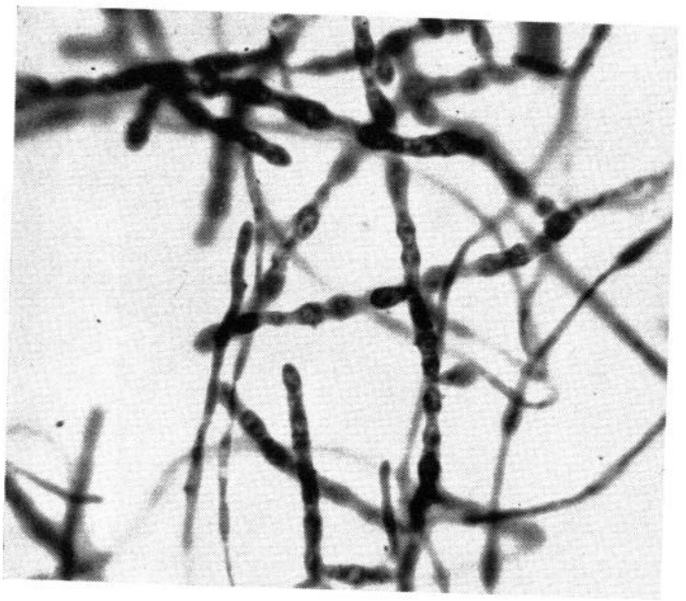
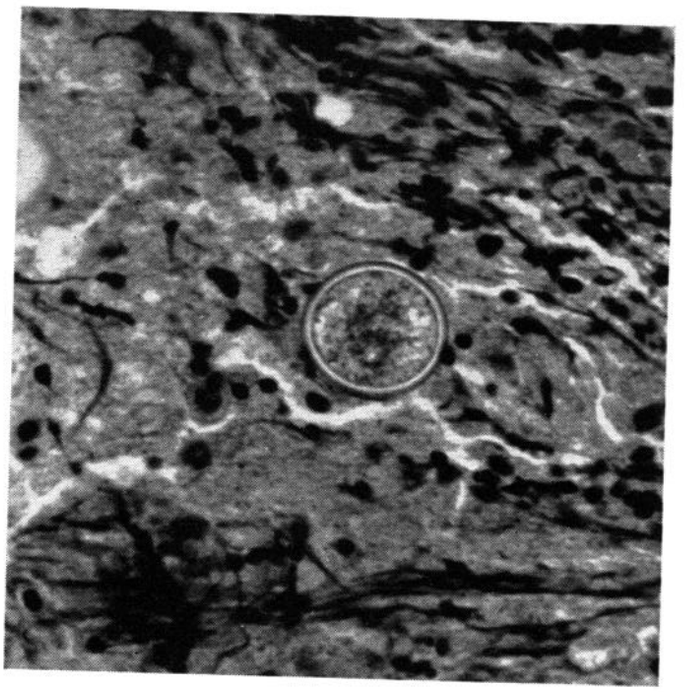


FIGURE 2 — Sporangium of *Coccidioides immitis* in tissue section of lung of infected dog.



## General Ecologic Considerations

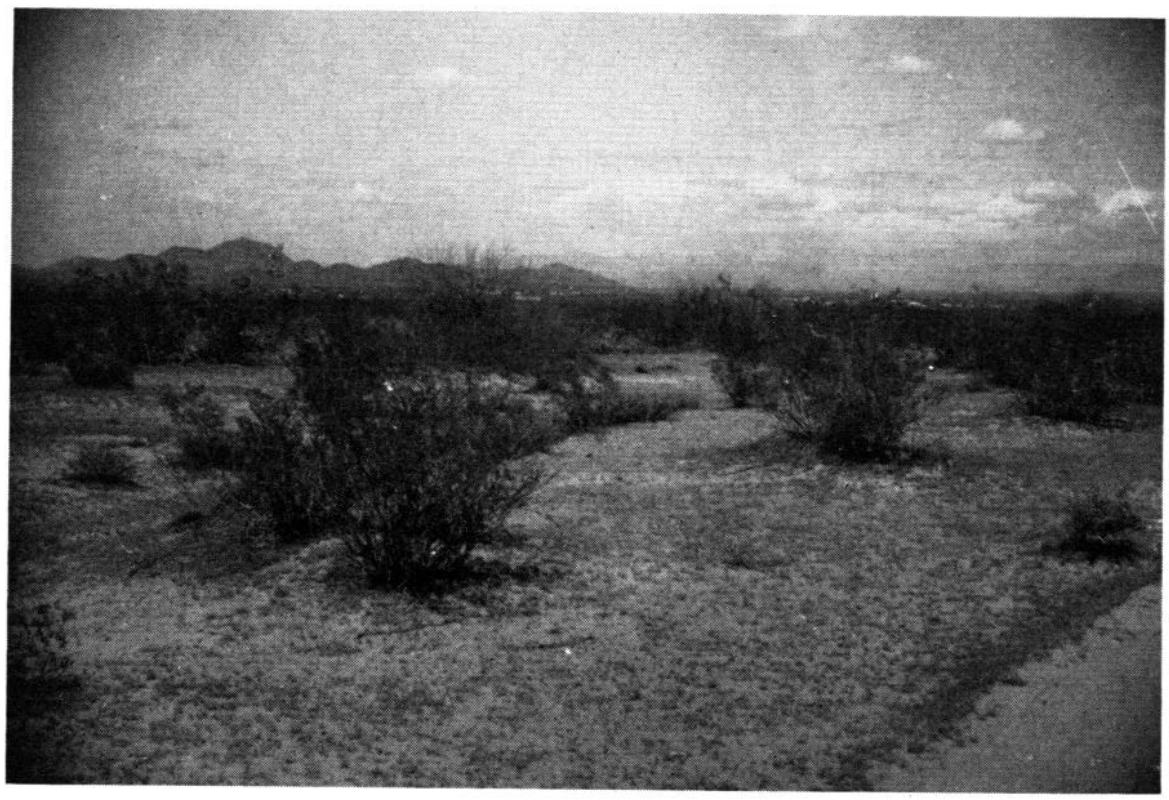
The present southwestern desert areas of the United States and portions of northern Mexico had a humid climate in recent past geologic ages. It appears that with the change to an arid and semiarid climate, only those organisms able to adapt to the new environment were able to survive. Aridity is said to serve as a stimulus to plant evolution (4). Under such a stimulus eventually there are likely to evolve specially adapted animals, plants, and fungi. Emmons and Ashburn (5) have speculated that *Haplosporangium parvum*, a fungus found in various parts of the United States and Canada, may have mutated under desert conditions to produce *C. immitis*. Biologists refer to the migration of some of the species of plants and animals from the main part of the southwestern deserts (Mohave and Sonoran) east over the Continental Divide into the Chihuahuan Desert in southern New Mexico and into western Texas. Migration of flora and fauna westward from the main southwestern desert area into the San Joaquin Valley and into some of the coastal valleys of California is said to have occurred also. Seeds and spores of plants and fungi are carried on the bodies and in the digestive tracts of animals that migrate into areas suitable for their existence, and if conditions are favorable in the new environment, these flora multiply.

Perhaps *C. immitis* originated in the area now known as central Arizona, which seems most favorable for its existence. It possibly has migrated to all favorable environments in the Southwest through the centuries. With some adaptive changes, the fungus may migrate farther east in Texas and farther north in California within the next several thousand years. In any case, the spread of the endemic area should concern man very little, considering the many years that are likely to be necessary for such expansion.

Most of the early studies on coccidioidomycosis dealt with the San Joaquin Valley. Many medically trained persons think of this infection when the valley is mentioned. As other areas are found to be endemic, the thought that comes to mind is that the fungus has recently migrated to these "new" areas. But what is "new" to man is not necessarily "new" in nature.

It is remotely possible that the fungus was originally brought to these deserts from other areas in dust on the bodies of migratory

FIGURE 3 — Typical scene in the Lower Sonoran Life Zone. The creosote bush (*Larrea tridentata*) is an important indicator plant in the flora of the life zone.

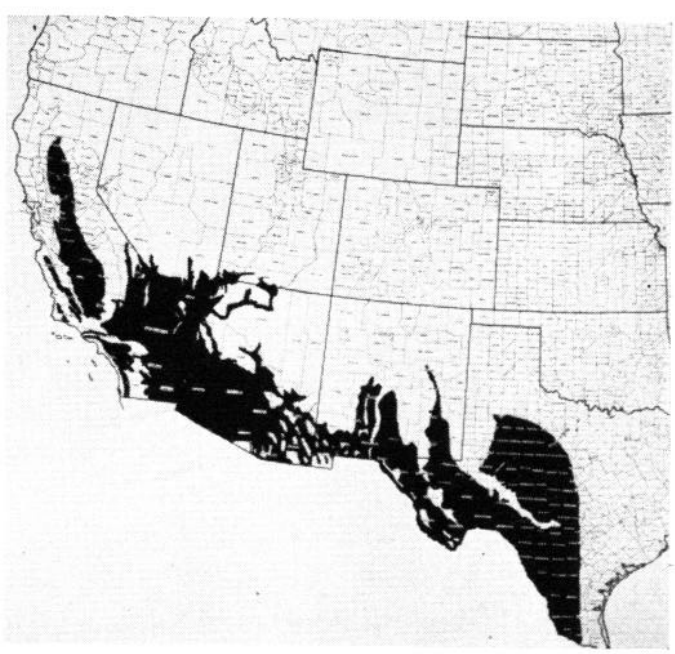


birds. One of the main indicator plants, the creosote bush, also exists in the desert areas of South America. It is of the same genus, but some botanists say it is a different species. It would be of interest to study other desert areas of the world for flora identical or similar to that indicative of the Lower Sonoran Life Zone.

Egeberg (6) has suggested the following to be favorable for a coccidioidomycosis endemic area: very hot summer months, mild winter weather, period of precipitation, a soil with sparse vegetation which results in much dust, and winds.

Egeberg and Ely (7) reported a soil-sampling survey for *C. immitis* in an area of the southern San Joaquin Valley of California. More soil specimens were found positive at the end of the rainy season that at the end of the dry season. Soil specimens taken in or near rodent burrows, especially at the end of the wet season, were more likely to be positive than samples taken from soil sites at random. A similar study near Phoenix, Arizona, by the author resulted in like findings.

FIGURE 4 — The Lower Sonoran Life Zone of the United States of America. The endemic area for coccidioidomycosis is within this zone and covers most of it.



Lubarsky and Plunkett (8) reported that *C. immitis* grows better in sterilized soil than in non-sterilized soil, and that it grows on sand as well as on dead vegetation. They

demonstrated in the laboratory that soils from various places in the United States supported the growth of *C. immitis* and that temperatures as high as 42° C. and as low as −20° C. did not destroy the fungus as long as it was already growing in a soil sample. They also found that the fungus grows throughout the pH ranges of most soils. Plunkett (9) has stated that, although the ideal conditions for maximum growth and sporulation of *C. immitis* can be determined in the laboratory, the true ecology of this fungus can be learned only by studying the organism in its natural habitat.

Friedman *et al.* (10) studied the effects of various temperatures, humidities, and amounts of salt in the media on one strain of *C. immitis*. Dry spores were stored at temperatures from −15° to 37°C. with relative humidities from 10 to 95%. There was little loss in viability of the organism at any temperature less than 37°C. until the sixth month, at which time there was a decrease of not more than 50% from the initial count. Environments of 10% humidity and 37°C. were deleterious, but all spores were not killed until 6 months had passed. At 50°C., all spores were dead in 2 weeks. Long storage of dry spores followed by subjecting them to extremes of temperature resulted in little loss of viability unless a second storage period followed. Storage of spores in physiologic saline solution for similar times and similar extremes of temperatures resulted in more rapid loss of viability; at 4°C., the spores were fully viable 6 months later. Spores suspended in distilled water at 4°C. remained viable for 11 months. In saturated sodium chloride solution at 4°C., there was little reduction in viability, but at 37°C. the rate of death was quite rapid. These studies indicate that *C. immitis* has adaptive features that help it to survive in an arid habitat.

Soil-sampling studies undertaken by one of the authors (Maddy) in cooperation with the Arizona State Department of Health indicate that *C. immitis* is rarely isolated from irrigated, cultivated soil in the endemic area. So far, it appears that *C. immitis* can be isolated with certainty only from in and around rodent burrows (and occasionally from noncultivated desert soil not near rodent burrows) in widely scattered areas in the desert.

Apparently *C. immitis* can grow only where there is a definite period of very hot weather during which there is little or no rainfall. During this period of time, the surface soil becomes partly sterilized. *C. immitis* remains viable just below a sterile layer of soil, as well as in the more moist and nitrogen-richer environment of desert rodent burrows. When rain does eventually fall, the humidity in the surface soil probably approaches the optimum for the growth of the fungus. Then *C. immitis* seems to grow well until other soil microorganisms interfere with its propagation or until the soil dries. The fungus probably still grows for a while in the cracks and holes of the earth until both the humidity in these sites drops and antibiotic action impairs its growth. The environment becomes highly infective with winds picking up dust and arthrospores and carrying them about. A study of prevailing winds over the entire endemic area does not give any clue to spread of the fungus. Probably it cannot remain viable for long periods of time when air-borne. A majority of the human and animal infections seem to occur during the windy, dusty weather following the wet season. The sun again begins sterilizing the surface soil and the infection rates begin to drop. Some infections still occur in the season between peaks of infectivity, these sometimes result from digging in the soil and exposing viable spores.

The amount of rainfall is apparently not as important as the precipitation effectiveness which is determined by runoff, evaporation, temperature, vapor pressure, and other factors such as the seasons during which the rainfall occurs. Suitable moistening of the topsoil at the time or seasons of the year when the temperature is most ideal, results in the development of topsoil humidity and

warmth conditions that are optimum for certain plants, fungi, and bacteria (11).

The three most infective areas for coccidioidomycosis in the United States as indicated by the skin-test study of Edwards and Palmer (12) include Kern County, California, Pima, Pinal, and Maricopa counties in Arizona, as well as the counties in Texas extending southeast from the southeast border of New Mexico to a point just beyond Laredo, Texas.

The measured rainfall in these three heavily endemic areas in the United States differs, but the effective precipitation among areas appears to be far less disparate. The type of soil has a good deal to do with its water-holding capacity. The soil group almost synonymous with the Lower Sonoran Life Zone is designated the "reddish soil of the semi-arid to arid southwest." This is a group made up of red desert, reddish-brown, and noncalcic brown soils with much lithosol (13). The soil within a locality can vary considerably in type and consistency and, consequently, in the amount of rainfall necessary to maintain a given amount of moisture in the topsoil for a certain period of time.

Looking for human cases and conducting coccidioidin tests on persons are of value in determing the infection potential of an area, however, man moves about considerably and this has its shortcomings. Looking for animal cases is of value. Coccidioidin testing of home-raised animals such as cattle has proven to be of considerable value in determing the infection potential of an area (14).

Observation of the flora and fauna is of value in assessing the potential infectivity of an area. It is desirable to examine the soil type and color and to take a series of soil temperature and moisture determinations over an extended period of time. The latter is seldom practical, and thus a study of the available climatic data is useful, particularly to ascertain a combination of three factors. These are the average temperature of the coldest month, the average temperature of the hottest month, and the average annual rainfall. The average temperatures of the hottest month of areas of high infectivity are above 80°F. (26.7°C.). Some infection has occurred in areas with temperatures as low as 77°F. (25°C.) but seldom where it is lower.

The average temperature of the coldest month is above 45°F. (7.2°C.) in areas of high infectivity. Some infection occurs where the temperature is as low as 35°F. (1.7°C.) but rarely below this. The annual rainfall varies from 5 to 20 inches (127–508 mm.) in the more endemic areas. As rainfall decreases to less than 5 inches (127 mm.), infectivity of the area drops. It appears that infections do not occur in areas with more than 20 inches (508 mm.) of rainfall unless there are particularly high temperatures or long dry periods to reduce the precipitation effectiveness.

Several discussions of factors relating to the possible effects of climate and weather on the geographic distribution of *C. immitis* have been published (7, 8, 14–24). All the questions are far from answered and much more study is needed.

## Geographic Distribution

The etiologic agent *Coccidioides immitis* is believed to propagate only in the Western Hemisphere.

Infections have been reported in Paraguay (25), Argentina (26, 27), Venezuela (28), and possibly also in Peru (29), Honduras (24), Ecuador (26), Bolivia (30) and Guatemala (31, 32).

In the United States the endemic areas are in western Texas, southern New Mexico, southern and western Arizona, southwestern Utah, southern Nevada, and southern and central California (14, 19, 20 23, 29).

That portion of northern Mexico which has a common international border with the United States is mainly in the Lower Sonoran Life Zone and has biogeographical characteristics similar to that of the endemic areas for coccidioidomycosis in the United

States. Undoubtedly there are some areas in northern Mexico which have a high infection potential for mammals including man.

### Studies in Mexico

Some of the studies made in Mexico are summarized below.

Coccidioidin tests were made on 1100 patients from various states of the Republic while in the General Hospital in Mexico City (33). There were seven positive reactors from Sinaloa and lesser numbers of doubtful interpretation for 21 other states.

Glusker *et al.* (34) coccidioidin tested soldiers from various states and reported positives as follows: Sonora—67%, Chihuahua—37%, Baja California—32%, and Colima—33%. Small percentages were reported from the states of Aguascalientes, Chiapas, Guerrero, Guanajuato, Hidalgo, Jalisco, Michoacan, Nayarit, Oaxaca, Queretaro, San Luis Potosi, Tlaxcala, Veracruz, and Yucatan.

Madrid (35) coccidioidin tested 248 persons at Hermosillo, Sonora, and found 15 males and 11 females positive.

Gonzales-Ochoa (36) coccidioidin tested 495 subjects of Hermosillo, Sonora, and Mexicali and Pueblo Nuevo in Baja California; 17.21% of these gave a positive reaction, but when those who had spent some time in the endemic zones of the United States were eliminated, the percentage was reduced to 13.4%.

Ochoa *et al.* (37) tested 667 persons in Jalisco and found 13.77% coccidiocidin positive.

Ortega-Fernandez (38) coccidioidin tested 400 persons in Rayon, Sonora, and found 74.5% positive.

Slim-Villegas and Aranda-Reyes (39) coccidioidin tested persons in the Mexicail Valley where 16.5% were positive with little differences noted, whether the major residence history had been urban or rural, and with 18.1% positives for males and 15.0% positives for females.

For Mexico, Gonzalez-Ochoa (40–42) indicated that the endemic zone of coccidioidomycosis probably encompasses the states of Baja California, Baja California Sur, Sonora, Chihuahua, Coahulia, Nuevo Leon, Tamaulipas, and possibly a portion of the state of Colima. For the northern states, Gonzales-Ochoa (40) indicated that there appears to be a decrease in infectivity from west to east.

Lavalle (43) and Acenes *et al.* (44) summarized the data on a number of human cases diagnosed in Mexico. Most persons so diagnosed, besides having a history of residence in the supposed endemic area in Mexico, often also have had a history of a visit to the endemic area in the United States.

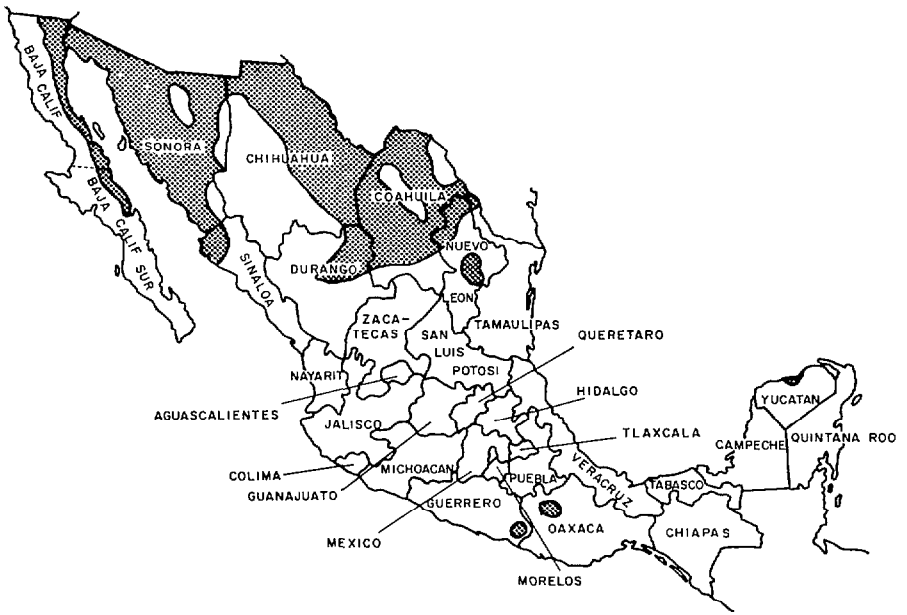
### Probable Endemic Area

Weather data for Mexico were examined. The areas of higher rainfall tend to be southerly and coastal, with the more arid areas tending to be northerly and to the interior of the country. In the more humid areas of the country, histoplasmosis is known to occur. In several areas where coccidioidin tests have been made, it is conceivable that positive coccidioidin tests were in fact cross-reactions due to histoplasmosis infections. This could have been the case in Colima where the rainfall averages 1000 mm. per year.

It is conceivable that if temperatures are quite high and there are a number of consecutive months almost completely devoid of rainfall, it is possible that *C. immitis* will propagate in nature even if the total rainfall is more than 508 mm. for the year. Most locations in Colima have average temperatures of more than 25°C. in the hottest month, and a number of the places have 5 to 7 months with little or no rainfall, so it might be possible that an endemic area could exist in Colima and in some similar sites in Mexico, but this is not very likely.

It is recognized that the weather data available to us from some states was rather

FIGURE 5 — The shaded areas are those parts of Mexico where there is a strong probability that *Coccidioides immitis* exists in nature.




sketchy and a number of unrecorded sites could exist with suitable rainfall and temperature combinations.

All weather stations in Mexico for which data were examined had suitably high average temperatures for the coldest month to meet the criteria set, so that the primary examination of data was concerned with the average annual rainfall and the average temperature of the hottest month (Fig. 5). As with U. S. Weather Bureau data, some weather stations in small rural sites are not shown on most maps, so that pin-pointing of some sites is not possible on maps other than those available from the weather agency.

*States with Sizable Areas with a Potential for C. Immitis Propagation*

*Sonora.* This state probably has the largest endemic area for coccidioidomycosis of all the states of the Republic. Except for a few high altitude places, such as Cananea which have summers which are too cool and a few areas in the eastern part of the state which have too much rainfall, there is considerable potential for *C. immitis* propagation in this state. The central portion has the highest potential. The northwestern portion, although hot and dry, is in fact too dry for a maximum potential. Places such as the following are probably endemic sites: Altar, Atil, Bacoachi, Carbo, Empalme, Etchojoa, Esperanza, Guaymas, Hermosillo, Magdalena, Moctezuma, Naco, Navojoa, Nogales, Ciudad Obregon, Ontagota, San Luis, Santa Ana, and Tecoripa.

*Baja California* and *Baja California Sur.* Available weather data was somewhat sketchy for this part of the country and particularly for Baja California Sur. All areas appear to be suitably arid. The areas that are also sufficiently hot enough are along the eastern coast to as far south as Mulege and as far north as the California border with the Mexicali valley having a fairly substantial potential for propagation of *C. immitis.*

*Chihuahua.* A sizable part of this state probably has areas which support the growth of *C. immitis.* This is particularly true of the northeastern part of the state which adjoins

Texas and somewhat less so for the southwestern areas with higher altitudes. Some weather stations indicating this potential are at: Camargo, Carillo, Casas Grandes, Chihuahua, Ciudad Juarez, Ojinaga, San Buenaventura, and Gonzalez Villa.

*Coahuila.* This state also has a sizable potential for the propagation of this fungus. Almost all portions of the state are involved. Some weather stations with this potential are: El Burro, Concordia, Cuatro Cienegas, La Flor, La Joya Hacienda, Don Martin, Matamoros, Monclova, Nueva Rosita and Sierra Mojada.

*Nuevo Leon.* Reports from almost all weather stations in this state indicate summer conditions hot enough except for some of the higher altitude places and some station data indicate sufficient aridity for propagation of this fungus. Examples of probable suitable sites include: Camaron, Lampazos, Montemorelos, Rayones, and Villa Aldama.

*States with Some Suitable Sites for the Propagation of C. Immitis*

*Tamaulipas.* Reports from all stations in this state indicated sufficiently high summer temperatures but only the Nuevo Lareado area was reported dry enough.

This state and all those previously mentioned comprise all the states that have a common border with the United States. All the areas in Mexico listed above as having a probable potential for the growth of this fungus adjoin known or suspected endemic areas in the United States. To the immediate south of this first tier of states in Mexico are several states with several areas both hot and dry enough to be considered as potential areas.

*Sinaloa.* This state adjoins Sonora to the south. All areas are hot enough and some sites which are also dry enough include: Ahome, Quila, and Topolobampo.

*Durango.* This state adjoins Chihuahua to the south. The west side of Durango has higher altitude areas with a cooler and more moist climate than that of the eastern side. Lerdo, Nazas, and Rodeo in the eastern side of the state appear to have a suitable climatic potential.

*States with Weather Data Indicating One Potential Site*

The main potential area is in the northern part of the country but three states considerably to the south have at least one possible site each.

*Guerrero.* Most weather stations in this state are at sites which have hot enough summers but most have too much rainfall. Only Ometepec (which is 120 kilometers east of Acapulco) is both hot and dry enough.

*Oaxaca.* A number of sites have hot enough summers but all appear to receive too much rain except for Cuicatlan.

*Yucatan.* Almost all places in this state are hot enough but only Progreso is recorded as being arid enough.

*State with no Recorded Potential Sites but still Suspect*

Some states have a number of sites which are dry enough and a number of other sites which are hot enough, but from the data available on a limited number of weather stations, sites with both conditions have not been reported yet.

*Puebla.* Most sites are too cold and wet but some are hot enough and some others are dry enough.

*San Luis Potosi.* Some sites are hot enough and some others are dry enough.

*Veracruz.* Many places are hot enough. Perote is dry enough but the summers are too cool there.

*States with Little or no Potential for Propagation of C. Immitis*

*Aguascalientes.* All sites have too low temperatures and almost all have too much rainfall.

*Campeche.* All sites have sufficiently hot summers but all receive an excess of rain.

*Colima.* All listed sites have warm enough climate but there is too much rain.

*Chiapas.* Most sites have a warm enough climate but all have too much rain.

*Distrito Federal.* All sites are too cool in the summer and most receive too much rain.

*Guanajuato.* Although a few places are dry enough, all are too cool in the summer.

*Hidalgo.* Here many places are dry enough but all have summers which are too cool.

*Jalisco.* Such places as Cabo Corrientes, La Esperanza and Puerto Vallarta have hot enough summers but all sites in this state are too wet.

*Mexico.* All sites are too cool in the summer and almost all sites are too wet.

*Michoacan.* Some sites are hot enough in the summer but all sites receive too much rain.

*Morelos.* Some sites are hot enough in the summer, but all are too wet.

*Nayarit.* Some sites have warm enough summers but all have excess rainfall.

*Queretaro.* Some sites are dry enough but all have summers which are too cool.

*Quintana Roo.* All sites reported on have hot enough summers but all are much too wet.

*Tabasco.* All sites get hot enough in the summer but all receive too much rain.

*Tlaxcala.* All sites are too cool in the summer and most sites are too wet.

*Zacatecas.* Although some places are dry enough, all of them have summers which are too cool.

**Summary**

An analysis of areas in the United States where coccidioidomycosis is endemic reveals relationships to various bioclimatological factors. A combination of three factors, 1) average temperature of hottest month—77°F. (25°C.) or higher, 2) average temperature of the coldest month—35°F. (1.7°C.) or higher, and 3) rainfall of 20 inches (508 mm.) or less, have been found useful in predicting the probable potential for *Coccidioides immitis* propagation in nature.

These three factors were used in considering climatic data for weather stations in all parts of Mexico. All stations were found to exceed the minimum winter temperature criterion. The combinations of the other two criteria were examined in detail.

States designated as having sizable areas with a potential for *C. immitis* propagation are: Sonora, Chihuahua, Coahuila, Nuevo Leon, Baja California, and Baja California Sur.

States designated as having some suitable sites are: Tamaulipas, Sinaloa, and Durango. States with one suitable site: Guerrero, Oaxaca and Yucatan.

States with no recorded potential sites but still in a suspect category are: Puebla, Veracruz, and San Luis Potosi.

States with little or no potential are: Aguascalientes, Campeche, Colima, Chiapas, Distrito Federal, Guanajuato, Hidalgo, Jalisco, Mexico, Michoacan, Morelos, Nayarit, Queretaro, Quintana Roo, Tabasco, Tlaxcala, and Zecatecas.

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## Probable Distribución Geográfica del *Coccidioides Immitis* en México (*Resumen*)

Un análisis de las zonas estadounidenses donde la coccidioidomicosis es endémica indica que existe una relación con diversos factores bioclimáticos. Una combinación de los tres factores, 1) temperatura media, en el mes más cálido, de 77°F (25°C.) como mínimo, 2) temperatura media, en el mes más frío, de 35°F. (1,7°C.) como mínimo, y 3) índice pluviométrico de 20 pulgadas (508 mm.) como máximo, ha resultado de utilidad para pronosticar la posibilidad de propagación del *Coccidioides immitis* en la naturaleza.

Estos tres factores fueron utilizados al considerar los datos climáticos correspondientes a estaciones meteorológicas de todo México. Resultó que en todas las estaciones la temperatura invernal mínima excedía del criterio establecido al respecto. También se examinaron detalladamente las combinaciones relativas a los otros dos criterios.

Los Estados donde se indicó que hay vastas zonas con posibilidades de propagación de *C. immitis* son: Sonora, Chihuahua, Coahuila, Nuevo León, Baja California del Norte y Baja California del Sur.

Los Estados donde se indicó la existencia de algunos puntos propicios a la propagación son: Tamaulipas, Sinaloa y Durango. Los estados donde hay un solo punto: Guerrero, Oaxaca y Yucatán.

Los Estados donde no se indicaron puntos de transmisión posible, si bien todavía se abrigan sospechas con respecto a ellos son: Puebla, Veracruz y San Luis Potosí.

Los Estados cuyas posibilidades son escasas o nulas son: Aguascalientes, Campeche, Colima, Chiapas, Distrito Federal, Guanajuato, Hidalgo, Jalisco, México, Michoacán, Morelos, Nayarit, Querétaro, Quintana Roo, Tabasco, Tlaxcala y Zacatecas.