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| | | |
|---|---|---|
| Corresponding Author | Family Name | **Trappe** |
| | Particle | |
| | Given Name | **James M.** |
| | Suffix | |
| | Division | Department of Forest Ecosystems and Society |
| | Organization | Oregon State University |
| | Address | Corvallis, OR, 97331-5752, USA |
| | Division | USDA Forest Service, Pacific Northwest Research Station |
| | Organization | Forestry Sciences Laboratory |
| | Address | Corvallis, OR, 97331, USA |
| Author | Family Name | **Kovács** |
| | Particle | |
| | Given Name | **Gábor M.** |
| | Suffix | |
| | Division | Department of Plant Anatomy |
| | Organization | Institute of Biology, Eötvös Loránd University |
| | Address | Pázmány Péter sétány 1/C, 1117, Budapest, Hungary |
| Author | Family Name | **Weber** |
| | Particle | |
| | Given Name | **Nancy S.** |
| | Suffix | |
| | Division | Department of Forest Ecosystems and Society |
| | Organization | Oregon State University |
| | Address | Corvallis, OR, 97331-5752, USA |




Abstract

The four major deserts of North America are situated in the western USA and northern Mexico: the Great Basin Desert, Mojave Desert, Sonoran Desert, and Chihuahuan Desert. Together they cover about 1,244,000 km$^2$. Two genera of North American desert truffles, *Carbomyces* with three species and *Stouffera* with one, are endemics. A third genus, *Mattirolomyces* with one endemic species in North America, occurs in

both northern and southern hemispheres from mesic forests to semiarid and arid habitats in three other continents. The largest and also the coldest of the North American deserts, the Great Basin Desert, and the smallest and hottest Mojave have each produced only one desert truffle collection so far. The Sonoran, also relatively hot, accounts for only two. In contrast, the relatively cold Chihuahuan, which extends from southern New Mexico south into Mexico's central plateau, has produced 17 truffle collections from New Mexico and about 30 from Chihuahua. Too little data are available on habitat requirements of the North American desert truffles to explain this skewed distribution. However, it likely reflects a concentration of early collecting efforts around the Jornada Basin Long-Term Ecological Research Site, originally established in 1912, that has attracted desert researchers for a century. Ten of the 17 collections in the Jornada vicinity were found by mycologist W. H. Long and his students and associates in 1941. More recently, active collecting in the Chihuahuan Desert of Chihuahua, Mexico, has added about 30 desert truffle collections. Both seem to reflect a convergence of the right people at the right place in a good truffle year.

# Chapter 8
# Ecology and Distribution of Desert Truffles in Western North America

**James M. Trappe, Gábor M. Kovács, and Nancy S. Weber**



## 8.1 Introduction

The four major North American desert regions occur in the far west of the continent (Fig. 8.1). The Great Basin Desert (411,000 km$^2$) extends from southeastern Oregon and southern Idaho through Nevada, much of Utah, southwestern Wyoming, far western Colorado, the northwestern corner of New Mexico, and far northern Arizona. The Mojave (65,000 km$^2$) occupies southeastern California, southern Nevada, and part of western Arizona. The Sonoran (313,000 km$^2$) reaches from southeastern California and southwestern Arizona south into Baja California and northwestern Mexico. The Chihuahuan (455,000 km$^2$) extends from south central New Mexico and western Texas into the central Mexican plateau. Altogether, these desert systems cover about 1,244,000 km$^2$ (Britannica online 2012), somewhat less than the Australian Outback deserts or a bit more than the Kalahari (see Chaps. 13 and 14). Adding the area of semiarid land associated with these deserts would probably increase the total of very dry habitats to more than 2,000,000 km$^2$ in North America.

Two truffle genera, *Carbomyces* and *Stouffera*, together comprising four species, have been reported from these deserts (Trappe and Weber 2001; Kovács

J.M. Trappe (✉)
Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331-5752, USA

USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, OR 97331, USA
e-mail: trappej@onid.orst.edu

G.M. Kovács
Department of Plant Anatomy, Institute of Biology, Eötvös Loránd University, Pázmány Péter sétány 1/C, 1117 Budapest, Hungary

N.S. Weber
Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR 97331-5752, USA

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**Fig. 8.1** Map of North American deserts. Adapted from http://www.desertmuseum.org/books/nhsd_biomes_.php. April 2013

et al. 2011). *Mattirolomyces* with one species is tentatively included, having been collected in or near a desert habitat. We exclude from this chapter taxa occurring in riparian zones along rivers traversing deserts, on high mountains surrounded by the deserts but receiving enough precipitation to support xeric woodlands or forests (e.g., Fogel and Pacioni 1989; Kropp et al. 2012), and desert secotioid basidiomycetes not strictly hypogeous (Moreno et al. 2007).

## 8.2 North American Deserts

The North American deserts are characterized by high diversity. They extend more than 2,200 km from the northern edge of the Great Basin Desert at about 42° N. lat. in Oregon south nearly to the Tropic of Cancer at about 22° N. lat. at the southern margins of the Sonoran and Chihuahuan Deserts in Mexico (Fig. 8.1). West to east they lie in the rain shadows of the Cascade, Sierra Nevada, and Sierra Madre Occidental mountains, high north–south aligned ranges that intercept rainstorms blowing in from the Pacific Ocean. The broad Rocky Mountains and their subsidiary ranges rise to high elevations on the east boundaries of these deserts, capturing precipitation from continental storms to nourish forests but also producing localized rain shadows. In northwestern Mexico, the trade winds drop little precipitation, so that even the Baja California peninsula is mostly Sonoran Desert despite being surrounded by water on three sides (Phillips and Comus 2000).

These deserts have been inhabited by indigenous Americans for thousands of years. Major archeological sites abound, especially in Utah (Great Basin Desert), Arizona (Sonoran Desert), and New Mexico (Chihuahuan Desert): many of these cultures developed advanced agricultural practices that extensively influenced plant communities as far back as 3,000 years (Ford 1987; Phillips et al. 2000; Columbian Electronic Encyclopedia 2005). AU2

### 8.2.1 *Landscapes*

All of the North American deserts encompass mountain ranges, large and small. This diversity of topography engenders diversity of soils, climate, and vegetation.

The Great Basin Desert (Fig. 8.1) is the largest and northernmost of the four North American deserts and averages the highest elevations, which range from about 1,200 to 2,000 m or more in elevation between mountain ranges that may reach as high as nearly 4,000 m (USDA Forest Service 1994). Most of the Great Basin Desert creeks and rivers flow into low areas and disappear, creating lakes in wet years that dry into playas in dry years and saline lakes such as Utah's Great Salt Lake (Grayson 2011). Exceptions to drainage into the basin are in the north and northeast of the Great Basin Desert, where streams flow into the Snake River drainage to find their way to the Pacific Ocean, and in southeastern Utah and northeastern Arizona, where streams empty into the ocean-bound Colorado River. These exceptions are not part of the Great Basin geographically but are considered extensions of the Great Basin Desert. Magnificent canyons crisscross the Great Basin Desert, including the Grand Canyon of the Colorado and Canyonlands National Park.

At its south margin the Great Basin Desert merges into the Mojave Desert (Fig. 8.1), notable for California's Death Valley, the lowest place in North America at about 86 m below sea level. The Mojave is bounded to the west by the Sierra

Nevada range, including the highest peak of the lower 48 states, Mt. Whitney, elevation 4,420 m; to the north by the ranges that enclose Death Valley and the Great Basin; to the east by the Colorado Plateau; and to the south by the Sonoran Desert (Webb et al. 2009).

The Sonoran Desert (Fig. 8.1) extends south from the Mojave into southwestern Arizona and Mexico's Baja California peninsula and northwest mainland. It ranges from its hundreds of kilometers of ocean and gulf beaches to colorful canyons and mesas and boasts a wealth of cactus and shrub species. Spectacular canyons and the lower Grand Canyon of the Colorado traverse the Sonoran Desert. It has been said that the Sonoran region encompasses most of the world's biomes, from dry tropical forest through thornscrub, desert, grassland, chaparral, temperate deciduous forest, coniferous forest, and tundra (Phillips et al. 2000). Of these, the Sonoran desert and its ecotones with grassland and thornscrub are the potential habitats for desert truffles.

The Chihuahuan Desert (Fig. 8.1) is separated geographically from the other three North American desert regions. It extends from the Jornada Basin in south central New Mexico, east to far western Texas and the Rio Grande Basin and south between the Sierra Madre Occidental and Sierra Madre Oriental through the Central Mexican Plateau to slightly south of the Tropic of Cancer. The Chihuahuan Desert contains north–south mountain ranges with broad, intervening desert basins (Haystad et al. 2006). Much of the Rio Grande Basin is below elevation 910 m, but most of the rest of the Chihuahuan Desert ranges from 1,200 to 1,830 m (Lee et al. 2011).

The metropolitan areas within all four deserts profoundly change the habitats over their large surrounding areas. These include Boise, Idaho, Salt Lake City, Utah and Reno, Nevada within the Great Basin Desert, while Las Vegas, Nevada, strikingly exemplifies post-World War II urban sprawl in the Mojave Desert. The Sonoran Desert includes Phoenix, Tucson, and Yuma Arizona in the USA and Hermosillo, Sonora in Mexico. The Chihuahuan desert includes Albuquerque, New Mexico, and El Paso, Texas in the USA as well as Chihuahua and Durango in Mexico.

The geology of the huge extent of North American deserts is characterized by complex and often localized events, from seafloor depositions to tectonic, volcanic, and glacial, much of it ongoing. We cannot do justice here: suffice it to say that all of these deserts have developed extensive areas of sand potentially suitable for the desert truffles and their hosts.



### *8.2.2 Climate*

The North American deserts differ strongly in temperatures and rainfall due to latitude, elevation, and mountains that constrain maritime influences on weather. Moreover, the north–south alignment of the major mountain ranges leaves relatively little impediment to southward flow of arctic cold fronts. For purposes of this chapter, only the desert communities are considered. For example, the higher mountains studding the Great Basin Desert get enough precipitation to support

**Table 8.1** Average annual and monthly maximum and minimum precipitation for selected weather stations in North American Deserts (Western Regional Climate Center 2013; Colegio de postgraduados 2013)

| Weather station | Mean annual (mm) | Mean monthly max. (mm) | Month of mean annual max. | Mean monthly min. (mm) | Month of mean annual min. |
|---|---|---|---|---|---|
| GB—Burns, Oregon | 264 | 41 | Dec | 6 | Aug |
| GB—Reno, Nevada | 185 | 26 | Jan | 4 | Jul |
| MO—Las Vegas, Nevada | 106 | 19 | Feb | 3 | May |
| MO—Death Valley, California | 60 | 13 | Feb | 1 | Jun |
| SO—Phoenix, Arizona | 200 | 27 | Jul | 1 | Jun |
| SO—Yuma, Arizona | 76 | 42 | Jan | 1 | May |
| CH—Albuquerque, New Mexico | 240 | 40 | Jul | 10 | May |
| CH—ElPaso, Texas | 246 | 51 | Jul | 6 | Apr |
| CH—Chihuahua, Mexico | 327 | 87 | Aug | 3 | Feb |

*GB* Great Basin, *MO* Mojave, *SO* Sonoran, *CH* Chihuahuan

vegetation communities ranging from woodlands to forests to subalpine and alpine communities, but only the deserts will be discussed. Precipitation and temperatures are taken from the Western Regional Climate Center (2013) and the Colegio de Postgraduados (2013) as summarized online in Wikipedia (search "weather records" and name of city in Google).

As storms from the Pacific hit the Cascade and Sierra Nevada ranges, most of their moisture precipitates onto the western slopes, leaving the rain shadow to the east that produces the Great Basin Desert. The Burns, Oregon weather station at the northern edge of the Great Basin records an average yearly precipitation of about 264 mm (Table 8.1), mostly falling in November through March. The average maximum monthly temperature of 31 °C usually occurs in July (Table 8.2), as did the record high of 42°C. The average monthly low temperature is −9 °C, in January, which also produced the record low of −30°C. Further to the south, Reno, Nevada averaged only 190 mm annual precipitation and is somewhat warmer than Burns, Oregon in both summer and winter (Tables 8.1 and 8.2). The Great Basin Desert is the coldest of the North American deserts, with the growing season confined to summer months (Lee et al. 2011). Only one desert truffle collection is recorded there, and it was at its relatively warm southeast margin adjoining the Sonoran Desert.

Located at relatively low elevations in the rain shadow of the highest peaks of the Sierra Nevada, the Mojave Desert is notably drier and warmer than most of the

**Table 8.2** Average maximum and minimum monthly temperatures and extreme records for selected weather stations in North American Deserts (Western Regional Climate Center 2013; Colegio de postgraduados 2013)

| Weather station | Month max. (°C) | Month of mean max. | Record max. (°C) | Month min. (°C) | Month of mean min. | Record min. (°C) |
|---|---|---|---|---|---|---|
| GB—Burns, Oregon | 31 | Jul | 42 | −9 | Jan | −30 |
| GB—Reno, Nevada | 34 | Jul | 42 | −5 | Dec | −28 |
| MO—Las Vegas, Nevada | 40 | Jul | 47 | 4 | Dec | −13 |
| MO—Death Valley, California | 47 | Jul | 57 | −1 | Dec | −6 |
| SO—Phoenix, Arizona | 42 | Jul | 48 | 7 | Dec | −2 |
| SO—Yuma, Arizona | 42 | Jul | 51 | 7 | Jan | −4 |
| CH—Albuquerque, New Mexico | 33 | Jul | 42 | −4 | Dec | −27 |
| CH—El Paso, Texas | 36 | Jun | 48 | 0 | Dec | −22 |
| CH—Chihuahua, Mexico | 33 | Jun | 40 | 7 | Jan | −10 |

*GB* Great Basin, *MO* Mojave, *SO* Sonoran, *CH* Chihuahuan

Great Basin Desert to its North (Tables 8.1 and 8.2). At Las Vegas, the Mojave precipitation averages only 106 mm annual precipitation, the rainiest month on average being January with 17.5 mm. July produced the average maximum temperature at 40°C and the record high of 47°C. The hottest months have been June through September. The coldest months have been December and January at an average of 4°C, the record low being −13°C in January. The Mojave also contains Death Valley, the driest and hottest place in North America. Its average annual precipitation is 60 mm, and in most years some months receive none; 1919 and 1953 were totally rain-free, and no rain fell for 40 consecutive months in 1931–1934. Its record high temperature was 56.7°C in July 1913, the hottest temperature ever recorded worldwide (World Meteorological Organization 2013). July also produces the highest average temperature of 47°C. The coldest month in Death Valley is December, averaging −1°C.

The Sonoran comes close to rivaling the Mojave for heat and aridity. The Phoenix, Arizona weather station records an average annual precipitation of 200 mm; July averages the wettest month with 27 mm (Table 8.1); most of the rain falls in July through September when wet air surges in from the Pacific Ocean. The average monthly maximum temperature is 42 °C in July, the record high of 48°C also occurred in July (Table 8.2). The average monthly winter minimum is 7°C in December. Yuma, Arizona has similar ranges of precipitation and maximum temperatures as Phoenix, but the average minimum (16°C) is warmer, the record low is −4°C, somewhat colder than Phoenix. Cabo San Lucas in Baja California

Sur, Mexico, is near the tip of the Baja California Peninsula (data not included in Tables 8.1 or 8.2); its climate is moderated by the maritime environment with somewhat more rain, lower average maximum temperatures, and higher average minima than Phoenix or Yuma.

The Chihuahuan Desert extends more to the south than the other deserts but is generally at higher elevations than the Mojave and Sonoran Deserts. In their temperature patterns, the three Chihuahuan weather stations (Table 8.2) more closely resemble those of the Great Basin Desert far to the north than those of the intervening Mojave and Sonoran Deserts. The Chihuahuan stations report higher precipitation on average than the other three deserts, and their rainy season is in summer as is that of the Sonoran Desert, thus differing from the winter rains of the Great Basin and Mojave Deserts (Table 8.1).

## 8.3 North American Desert Truffles

### *8.3.1 History of Discovery*

The history of desert truffle discoveries in North America is relatively prosaic: no heroic exploring expeditions, no encounters with native tribesmen to reveal their use of truffles. This is not to say that indigenous people in North American deserts did not use truffles, it is only to acknowledge that no such use has been recorded. Moreover, some early collectors may have had adventures not recorded for posterity.

E. Forges found a truffle along the banks of the Red River in northwestern Louisiana in 1886. We know nothing about Forges, but the truffle collection was given to Rev. A. B. Langlois, of whom it was said "Louisiana is at this time the fortunate possessor of a most industrious and acute botanist in the person of Rev. A. B. Langlois, of St. Martinville" (Lamson-Scribner 1893). Langlois was a prolific collector of plants and fungi. His herbarium, now housed at the University of North Carolina, numbers about 20,000 collections (McCormick 2012). He, in turn, sent some of Forges' truffles to New Jersey mycologist Job Ellis, who in collaboration with B. M. Everhart had started the sets of exsiccata known as *North American Fungi* sent to dozens of herbaria around the world (Kaye 1986). Forges' collection was large enough to be split for inclusion in *North American Fungi Ser. 2* as Nr. 1782, *Terfezia leonis* (Tul. & C. Tul.) Tul. & C. Tul. The Californian mycologist H. W. Harkness had Nr. 1782 and concluded it was not *T. leonis* but rather a new species, which he described as *Terfezia spinosa* Harkn (Harkness 1899). Harkness' split of the Forges collection thus becomes the holotype of *T. spinosa*, now in the Harkness Collection in the US National Fungus Collections. The other splits scattered around the world are isotypes. The species rested with this name for more than a century, until Kovács et al. (2011) subjected it to phylogenetic analysis to demonstrate it belongs in the genus *Mattirolomyces.*

Louisiana is not a desert, so what is the relevance of this story? As we will show in the following section, *Mattirolomyces spinosus* occurs in or near North American deserts as well.

William H. Long of the US Bureau of Plant Industry was the first mycologist to specialize in fungi of the arid southwestern USA from his retirement in 1937 into the early 1940s. During those years he accounted for many collections of the desert truffle genus *Carbomyces* and the type species of *Carbomyces* and *Stouffera*, the latter named for his companion collector David J. Stouffer (Kovács et al. 2011). Helen M. Gilkey, for 50 years North America's renowned expert on truffle taxonomy, examined Long's ascomycete collections and determined them to represent a new genus. She described *Carbomyces* and two species, *Carbomyces emergens* and *Carbomyces longii* (1954). Later, Nancy Weber discovered that a third species had been misinterpreted as a basidiomycete, so it was named *Carbomyces gilbertsonii* in honor of the much respected Arizona mycologist, Robert Gilbertson (Trappe and Weber 2001). Meanwhile, North American desert truffles were collected sporadically and opportunistically until Mexican mycologist Marcos Lizárraga and his associates collected a large number of *Carbomyces* spp. in northern Mexico in 2008–2011 (Moreno et al. 2012). Occasional recent collections by others such as Robert M. Chapman in New Mexico have added to our knowledge of distributions, and phylogenetic analyses have clarified taxonomic relationships and revealed new taxa (Kovács et al. 2011).

## *8.3.2 Taxonomy, Endemism, and Distribution*

The desert truffle taxa discussed in this chapter are described in detail and illustrated by Trappe and Weber (2001), Kovács et al. (2011), and Moreno et al. (2012). Of the three genera of desert truffles known from North America, two are endemics (*Carbomyces*, *Stouffera*), whereas the third, *Mattirolomyces*, is widely distributed in both northern and southern hemispheres from mesic forests to semiarid and arid habitats (see Chaps. 13 and 14).

*Carbomyces* (Carbomycetaceae) contains three species, *C. emergens* Gilkey (Fig. 8.2), *C. gilbertsonii* N. S. Weber and Trappe, and *C. longii* Gilkey (Trappe and Weber 2001). The genus is readily differentiated from all other desert truffles worldwide by its brown asci that disintegrate by maturity. It occurs in the USA from New Mexico through Arizona to California in the Chihuahuan, Sonoran and Mojave deserts, respectively, and in the Mexican state of Chihuahua in the Chihuahuan Desert. The other two species are known in the USA only from the type collections. Both have recently been found in the Chihuahuan Desert in Mexico (Moreno et al. 2012).

*Stouffera*, with its single species *Stouffera longii*, is known only from the type locality in the southeast corner of the Great Basin Desert in northwestern New Mexico. Its spores are distinctive by being reticulate but with the spore surface within the reticular walls having minute rounded bumps (Kovács et al. 2011).

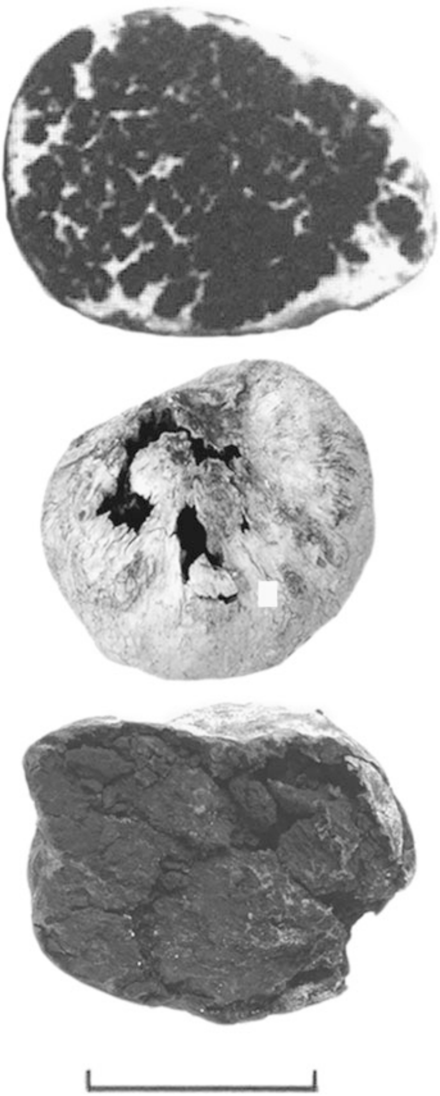

**Fig. 8.2** Ascomata of *Carbomyces emergens* from the Chihuahuan Desert. Scale bar = 25 mm. *Top*: cross-section of fresh ascoma showing white tramal veins separating dark pockets of asci and spores (image courtesy of John Zak and *Mycologia*). *Middle*: surface view of dry ascoma found lying loose on ground; note breaks in peridium (image courtesy of Robert M. Chapman). *Bottom*: cross-section of dry ascoma showing the powder of spores and collapsed asci (image courtesy of Robert M. Chapman)



Two species of *Mattirolomyces* have been found in North America, but only *M. spinosus* has been found in arid or semiarid environments (Kovács et al. 2011). As noted above in the history section, the type of *M. spinosus* was found along the banks of a river in Louisiana, not an arid habitat. However, the genus *Mattirolomyces* occurs in desert habitats in Australia and southern Africa (Trappe et al. 2010). One North American collection of *M. spinosus* was from Arizona, but included no data on time or specific location. For the present we do not know if it occurred in desert, semi-desert, dry woodland, or forest. Because Arizona is mostly occupied by deserts (Great Basin, Mojave, Sonoran), we elected to include *M. spinosus* here until its total distribution becomes better known.

Edibility of the North American desert truffles is unknown. Presumably they are not toxic in keeping with the edibility of the west Asian, northern African, southern African Kalahari, and Australian desert truffles. However, the North American species have mostly been found in a dry, powdery state that seems unpalatable.

### 8.3.3 Ecology: Key to Distribution

*C. emergens* (Fig. 8.2) is the only North American truffle documented well enough to offer a glimpse of its habitat. Notes accompanying collections by W. H. Long in the Chihuahuan and Mojave Deserts report its habitat variously as "hypogeous. . . in sandy soil on ridge. . .in soil on sagebrush area. . .in mesquite sandhill area" (mesquite is *Prosopis glandulosa* Torr., a member of the Fabaceae). Zak and Whitford (1986), who found *C. emergens* fruiting in the Chihuahuan Desert in the same general area where it had been collected 40 years earlier by Long, describe the habitat: "The site consisted of coppiced dunes vegetated with *Atriplex canescens* (Pursh) Nutt., *P. glandulosa* Torr., several spring flowering annuals, *Lepidium lasiocarpum* Nutt., and *Lesquerella gordonii* (Gray) Wats. The interdune spaces were generally devoid of vegetation. The ascocarps were discovered 2–5 cm below the soil surface in and around recent rodent digs located in the interdune areas."

That *C. emergens* was evidently dug by rodents suggests mycophagy as a means of spore dispersal. Given the time of year and habitat in which they found the rodent diggings, Zak and Whitford (1986) reckoned that spotted ground squirrels (*Xerospermophilus spilosoma*) might be the mycophagists (Fig. 8.3). This truffle also has an alternative method of spore dispersal. The species epithet *emergens* indicates that it can emerge through the soil surface. Once it emerges, it may dry in situ and be transported by wind or water. This is supported by notes on some of Long's collections: "Loose in sandy wash north of airport garbage dump. . .in wash where water washed (the ascocarps). . .loose in sand wash. . .on top of ground but loose." Zak and Whitford (1986) found ascocarps lying loose on the soil surface 15 km N of the original collection site. Dr. Robert Gilbertson provided a specimen of *C. emergens* for examination by Trappe and Weber (2001); he found it caught in a brush pile in his backyard at the edge of the desert (R. Gilbertson personal communication).

Clearly *C. emergens* indeed emerges and is moved around to be caught in arroyos, clumps of vegetation, brush piles, etc. The success of this mechanism for spore dispersal lies in its anatomy. The fresh ascomata studied by Zak and Whitford (1986) had a solid gleba, which was also evident in young specimens dried for herbarium accession. The tissues of these specimens rehydrated readily in the laboratory and consisted of large, thin-walled cells and asci (Trappe and Weber 2001). The ascomata lift themselves to the surface as they expand and the spores mature. As they dry in situ, they detach from the sand, and their inflated, thin-walled

**Fig. 8.3** Spotted ground squirrel, a likely eater of desert truffles in the Chihuahuan Desert. Adapted from http://commons.wikimedia.org/wiki/File:Spotted_ground_squirrel.jpg. April 2013

glebal hyphae collapse. When wind or water move them about, the peridia break open or are abraded away by sand while the glebae become reduced to a powder of spores and fragmented asci and tramal cells (Fig. 8.2). It is easy to envision this spore-bearing powder escaping through the broken peridia to be dispersed as the dry, wind-blown ascomata bounce along the ground.

The mycorrhizal hosts of North American desert truffles are unknown. The notes accompanying *Carbomyces* collections mention several common woody perennials that often occur together. All are regarded as forming arbuscular mycorrhizae or being nonmycorrhizal (Wang and Qiu 2006), although *Prosopis* has been found to be ectomycorrhizal as well in one case (Frioni et al. 1999). Desert truffles in the Pezizaceae, however, are recorded as forming unusual types of mycorrhizae on annual and perennial plants (see Chap. 5). DNA needs to be analyzed to resolve the question.

Trappe and Weber (2001) and Kovács et al. (2011) together list 21 collections of all species of North American desert truffles in the USA; Moreno et al. (2012) added about 30 from Mexico. As noted in Sect. 8.2, the Great Basin and Chihuahuan Deserts average the highest in elevation and coolest of the four North American deserts, the Mojave and Sonoran being generally warmer and drier. Other factors such as soils are little known in terms of truffle distribution, except that sands are indicated for those collections for which the substrate was recorded. Associated vegetation is similarly little recorded. Of the roughly 50 total collections, one each is from the relatively cool Great Basin Desert and the relatively warm Mojave, two are from the relatively warm Sonoran, and 46 from the relatively cool Chihuahuan.

Judging from data available to date, the most productive areas for North American desert truffles, specifically *C. emergens*, are within the Chihuahua desert, ranging from central New Mexico, USA south, to adjacent northern Chihuahua, Mexico, and that species may fruit any month of the year (Trappe and Weber 2001; Moreno et al. 2012). The Chihuahua desert has relatively high precipitation and cool temperatures compared to the other deserts (Tables 8.1 and 8.2). The relationship of specific fruiting events to weather phenomena needs more detailed examination to determine how seasonal weather patterns affect fruiting. The human factor also needs to be considered: both the New Mexican and Chihuahua high-production areas have had nearby academic and research institutions with active mycological research programs when and where most of the collections have been found. Other of the North American desert regions may prove to be productive as well, when the weather is right and collecting is vigorously pursued.

## 8.4 The Outlook for North American Desert Truffles

Prior to World War II, overgrazing by livestock and mining were the primary threats to truffles of the North American deserts. They changed composition of plant communities, promoted invasion of exotic weeds, compacted soil, and exacerbated fire hazard and erosion. Then the damming of rivers provided irrigation water that enabled expansion of agriculture. Since World War II urban sprawl, recreation, water overuse, energy development, road construction, and air pollution have gained prominence in environmental degradation of these deserts (Phillips et al. 2000; Haystad et al. 2006; Webb et al. 2009; Finch 2012; Ford 2012). Because so little is known about the habitat requirements of the North American desert truffles, it is impossible to specify how much these disturbances would affect desert truffle production other than to note that large areas of the ecosystems in which these truffles might have grown have been drastically affected or taken out of truffle production. 

As is true of most deserts, climate varies markedly over the course of the year and between years. Moreover, the changes will differ between deserts and habitats within those deserts. Climate change in the North American deserts has received considerable recent attention (Ford et al. 2012). The present climate models predict overall warming and drying for the North American deserts through 2090. Longer and more severe droughts will increase potential for "mega fires," susceptibility to insect pests and diseases, invasion of exotic weeds, and conflicts overuse of diminishing freshwater resources, to mention several. Some of these events may move habitats suitable for truffle fungi northward into the Great Basin cold desert from the warmer Mojave and Sonoran deserts. But desert truffle populations have not been systematically monitored so far and are not likely to be monitored in the future. With no solid baseline data in hand, we may never learn how climate change affects truffle populations in North American deserts except in a broad, hypothetical way.

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