

Catastrophic Freezes in the Sonoran Desert

Janice E. Bowers

Office of Arid Lands Studies
University of Arizona

Introduction

Freezing weather plays an important role in the Sonoran Desert. The effect of freezing on desert vegetation has been investigated by many workers, including Shreve (1910, 1911, 1912, 1914), Turnage and Hinckley (1938), Hastings and Turner (1965), Felger and Lowe (1967) and Steenbergh and Lowe (1976a, 1976b, 1977). The northern boundary of the Sonoran Desert, defined by the northern extent of characteristic Sonoran Desert plants such as Saguaro (*Cereus giganteus*), Triangle-Leaf Bursage (*Ambrosia deltoidea*), Canyon Ragweed (*Ambrosia ambrosioides*), Little-Leaf Palo Verde (*Cercidium microphyllum*) and Blue Palo Verde (*Cercidium floridum*), also coincides with the isotherm beyond which freezing temperatures have occurred which have lasted longer than 24 hours (Hastings, 1963). Duration and intensity of freezing temperatures determine the northern and eastern extent of Sonoran Desert vegetation (Shreve, 1914; Turnage and Hinckley, 1938).

Saguaro populations at the eastern margin of the Sonoran Desert have undergone demographic changes as a result of recurrent severe freezes between 1913 and 1971 (Steenbergh and Lowe, 1976a, 1976b, 1977). Steenbergh and Lowe conclude that severe freezes which kill large numbers of very young and very old individuals of Saguaro were not characteristic of the environment for 50 to 100 years before 1890. Catastrophic freezes damage or kill many other species as well, both at the margins of the Sonoran Desert and occasionally well into its center (Turnage and Hinckley, 1938; Jones, 1979).

During the past 100 years, the climate of the Southwest has become warmer and drier (Leopold, 1951; Hastings and Turner, 1965; Cooke and Reeves, 1976). Thus, subtropical plants in the Sonoran Desert in Arizona must either adapt to more xeric conditions and to recurring catastrophic freezes or be eliminated by drought and frost. Although it might seem that catastrophic freezes should cause the boundaries of the Sonoran Desert to shift to the south and west, the general trend toward a warmer and drier climate tends to prevent higher-elevation species from moving downslope to occupy the vacated habitat. It is possible that the margins of the Sonoran Desert have not dramatically shifted geographically, but that the composition and structure of plant associations at the margins have changed markedly due to the combined effects of catastrophic freezes and a more xeric climate.

Although many researchers have studied freezing in the Sonoran Desert, none have examined long-term weather data to determine the combined ef-

fects of freezing temperatures and duration of freezing on Sonoran Desert vegetation. This present paper will fill that gap by 1) defining catastrophic freezes in biological and climatological terms, and 2) correlating temperature records with observed catastrophic damage to Sonoran Desert plants during this century.

Methods

Since Steenbergh and Lowe (1976a) have stated that temperatures below 21°F are critical to survival of Saguaro, I tallied the number of nights since 1894 when temperatures at the University of Arizona weather station in Tucson fell below 21°F. In addition, I compiled hourly temperature data from Tucson International Airport for winters between 1946 and 1979. [*The hourly observations include data from January, 1946 to February, 1949; December, 1952 to December 1957; January, 1962 to January, 1979. Temperature observations were made at 3-hour intervals from January, 1965 to January, 1979.*] I also searched the literature for references to catastrophic freezes and frost damage to Sonoran Desert plants. These references were compiled into a chronology of catastrophic freezes in the Sonoran Desert (Appendix 1).

Results and Discussion

Winter temperatures fell below 21°F in Tucson 86 times between 1894 and 1979. Catastrophic freezes in which a wide variety of native plants over large areas of Sonoran Desert were killed or severely damaged were less frequent, only nine such freezes occurring between 1894 and 1979 (Appendix 1). Apparently, although freezing temperatures below 21°F kill juvenile and very old individuals of Saguaro (and possibly other Sonoran Desert plant seedlings as well), more severe conditions are necessary for catastrophic damage to occur. The problem, then, is to define catastrophic freezes in climatologic terms by discovering the combinations of low temperature and duration of freezing which cause catastrophic damage to Sonoran Desert plants.

Hourly temperature observations for 325 nights show that temperatures below 33°F at the Tucson International Airport lasted no longer than 9 hours on 85% of the nights, for 10–15 hours on 14% of the nights, and for 16 hours or longer on only 2% of the nights. Similarly, temperatures above 24°F occurred much more frequently than temperatures below 24°F. On 90% of freezing nights the minimum temperature was 25°F or higher (Figure 1). Hourly temperature observations also demonstrate that minimum temperature is loosely associated with

duration of freezing (Figure 2). Minimum temperatures of 28°F to 32°F are most frequently associated with a relatively short period of freezing (1–9 consecutive hours) and minimum temperatures of 20°F to 26°F are more frequently associated with a longer period of freezing (12–20 consecutive hours). The general pattern which emerges from these data is that most freezes in Tucson are brief and not very intense. The few freezes that are very cold also last longer.

Hourly temperature data correspond well with the biologically defined catastrophic freezes listed in Appendix 1. In most cases catastrophic freezes occurred when the lowest temperatures and the longest durations of freezing coincided (Table 1). For example, a freeze lasting 11 hours and reaching a minimum temperature of 22°F was recorded on February 4, 1955. This freeze was apparently not catastrophic. However, on January 11, 1962, a freeze with the same minimum temperature but lasting 19 hours was catastrophic. On January 17, 1949, freezing temperatures lasted for 15 hours, but the minimum at the airport never fell below 31°F. A later freeze on January 6, 1971 also lasted for 15 hours, but the minimum temperature was 18°F. The 1949 freeze was not catastrophic but the 1971 freeze was.

Table 1. Duration of some freezes at Tucson International Airport, 1946–1979. Data are from U.S. Weather Bureau, Local Climatological Summaries, Tucson, Arizona.

Date	Minimum Temp. (°F.)	Duration (Hours 32°F.)	Remarks
Jan. 28, 1948	26	14	
Jan. 29, 1948	26	13	
Jan. 4, 1949	17	20	Catastrophic (see Table 1)
Jan. 5, 1949	17	16	
Jan. 17, 1949	31	15	
Jan. 18, 1949	26	12	
Jan. 30, 1949	26	14	
Dec. 28, 1954	18	13	
Feb. 4, 1955	22	11	
Jan. 11, 1962	22	19	Catastrophic (see Table 1)
Jan. 12, 1964	19	12	
Jan. 4, 1971	18	18	Catastrophic (see Table 1)
Jan. 5, 1971	19	18	
Jan. 6, 1971	17	15	
Jan. 7, 1971	20	15	
Jan. 8, 1971	20	12	
Jan. 9, 1971	26	12	
Dec. 24, 1974	19	12	
Dec. 8, 1978	20	18	Catastrophic (see Table 1)
Dec. 9, 1978	23	15	

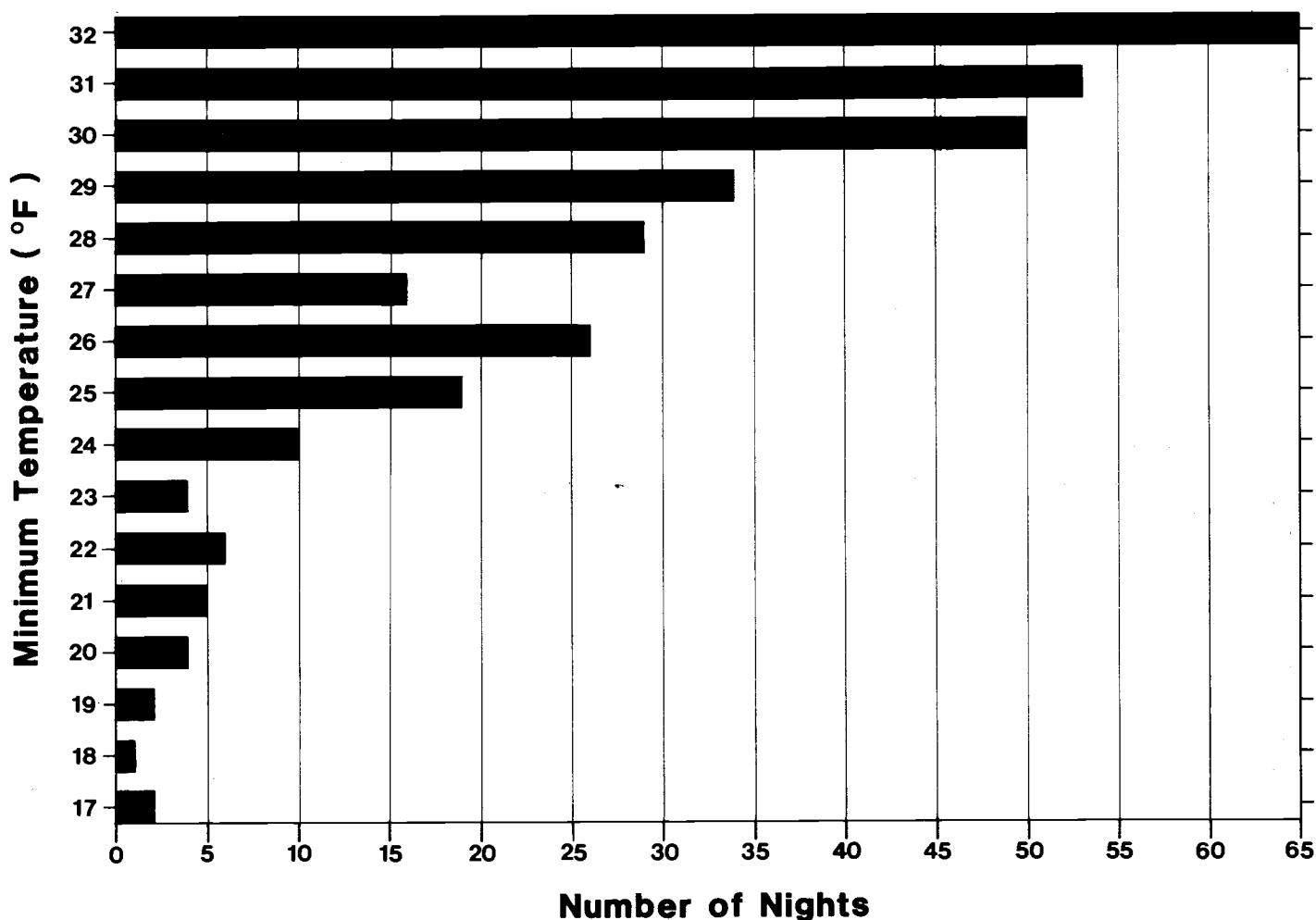


Figure 1. Number of freezing nights at Tucson International Airport, 1946-1979. Data are from U.S. Weather Bureau, *Local Climatological Summaries, Tucson, Arizona.*

Other characteristics of these particular freezes are also worth noting. First, the overnight freeze on January 17, 1949 was preceded and followed by nights that were not unduly cold. On the other hand, the catastrophic freeze of January 6, 1971 occurred on one of four consecutive nights of very cold weather. This is characteristic of the catastrophic freezes. Secondly, minimum temperatures vary from place to place across rather small distances. During the catastrophic freeze of January 11-12, 1962, the minimum temperature both nights was 22°F at Tucson International Airport, 7 miles south of the University of Arizona. At the University, the minimum was 24°F on January 11 and 20°F on January 12. The minimum temperatures were 20°F and 15°F on January 11 and 12, respectively, at the Campbell Avenue Farm, only 4 miles north of the University of Arizona.

Catastrophic freezes usually occur within 17 days of the winter solstice. Since there are more hours of potentially freezing darkness and fewer hours of relatively warm daylight during this winter solstice period, it seems likely that cold fronts moving into the Sonoran Desert on or about December 21 will be harsher than they would be in early December or late February. The longer nights mean that cold temperatures will be prolonged, occasionally with catastrophic results to native plants.

Summary

In the Sonoran Desert there is a gradient from mild freezes with little effect on native plants to severe freezes which inflict damage to frost-sensitive plants (such as juvenile or very old individuals of Saguaro), to catastrophic freezes which kill or injure many species of plants over large areas.

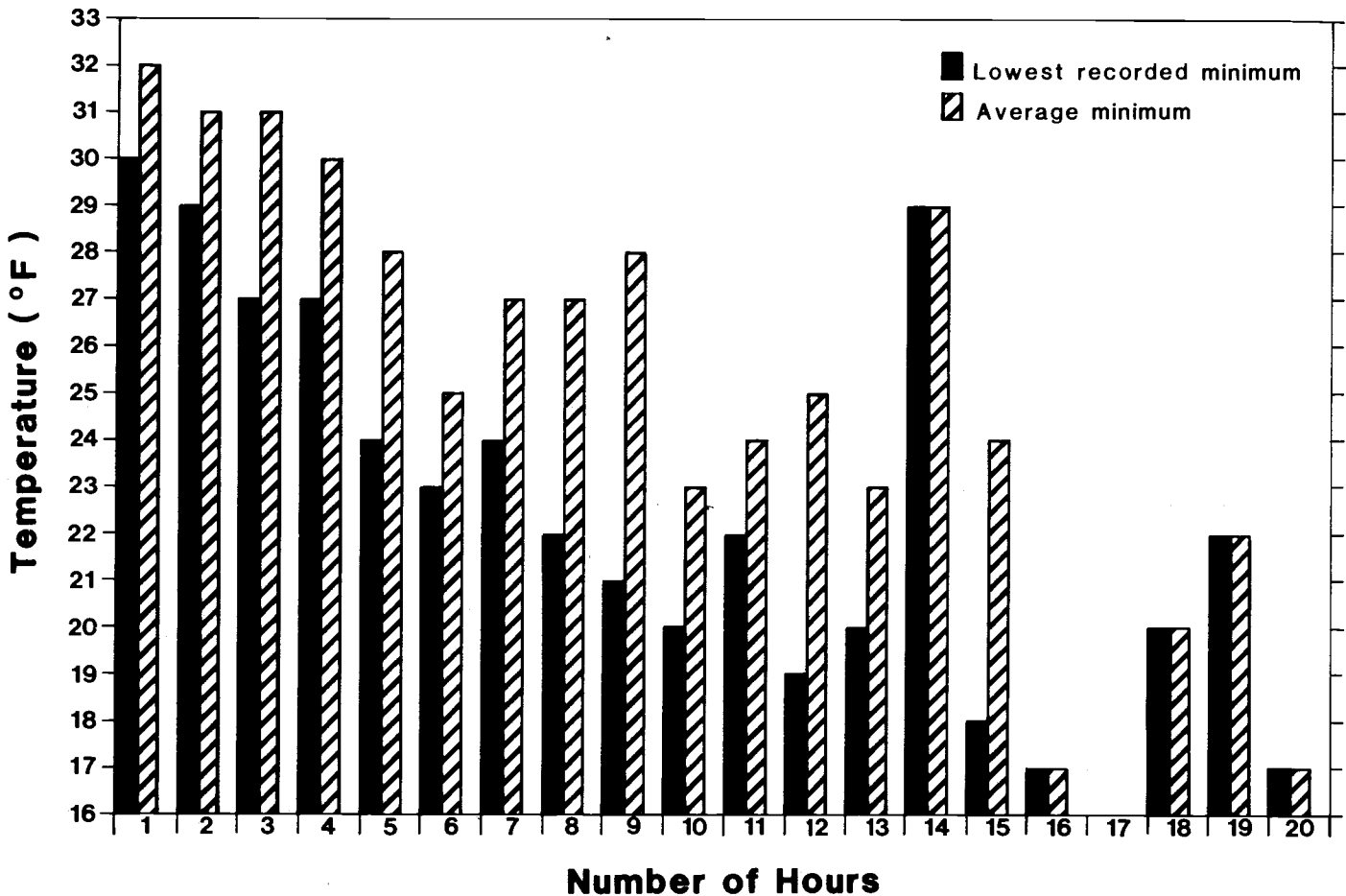


Figure 2. Correspondence of minimum temperatures with duration of freezing at Tucson International Airport, 1946-1979. Data from source in Figure 1.

Severe freezes are less frequent than mild freezes and catastrophic freezes are less common yet. Catastrophic freezes have occurred more frequently during the last 100 years than in the previous century and may have modified the structure and species composition of plant associations on the margin of the Sonoran Desert. An analysis of hourly temperature observations shows that catastrophic freezes occur when low minimum temperatures and many consecutive hours of freezing interact. Between 1946 and 1979, there were four freezes which lasted between 15 and 20 hours, reached minimum temperatures between 17°F and 22°F, and caused widespread frost damage to Sonoran Desert plants. These were catastrophic freezes.

Appendix 1. A Chronology of Catastrophic Freezes in the Sonoran Desert.

January, 1913. **Minimum Temperature:** 6°F in Tucson, 16°F in Phoenix, 11°F in Florence. **Duration:** 19 hours in Tucson, low temperatures "extended over a considerable portion of the night

preceded by nearly 24 hours of continuous freezing weather."

Observations of Damage to Plants: "Thousands of small giant cactus plants growing near their greatest altitudinal limits were killed outright. Many other species also suffered great damage."

Source: Turnage and Hinckley, 1938; Thornber, 1916.

January, 1937. **Minimum Temperature:** 10°-20°F in desert areas, 15°F in Tucson, 20°F in Altar, Sonora, 16°F in Carbo, Sonora; frost reported in Kino Bay, Sonora. **Duration:** 19 hours at Tumamoc Hill in Tucson; in addition the 1937 cold wave "lingered over an entire week." **Observations of Damage to Plants:** Between Sells and Ajo, *Olneya tesota*, *Celtis pallida*, *Ambrosia ambrosioides*, *Jatropha cardiophylla*, *Encelia farinosa*, *Sapium biloculare* and *Cereus thurberi* were damaged. Branch tips of *Cereus thurberi* at Gunsight Pass in western Pima County were frozen back 8-16 inches and lateral branches less than 12 inches long were completely killed. In southern Sonora, leaves and branches of *Ficus petiolaris*, *Randia echinocarpa* and *Pithecellobium dulce* were damaged. Leaves and branches of *Guazuma ulmifolia* and flowers of *Ipomaea arborescens* were damaged in central Sonora. **Source:** Turnage and Hinckley, 1938; Wiggins, 1937.

January, 1949. **Minimum Temperature:** 16°F at University of Arizona at Tucson, 17°F at Tucson International Airport. **Duration:** 20 hours at Tucson International Airport. **Observations of**

Damage to Plants: "This is the second coldest January that the state has experienced in its 55 years of climatic history ... A damaging freeze on the 4th, 5th and 6th resulted in heavy losses to fruits and vegetables in the southern part of the state." **Source:** U.S. Weather Bureau, 1949.

January, 1962. Minimum Temperature: 14°F at Organ Pipe Cactus National Monument, 20°F at Tucson International Airport. **Duration:** "Freezing temperatures continued after the first night through the next day and into the second night" on the south slope of the Santa Catalina Mountains between 2500 and 4500 feet. **Observations of Damage to Plants:** 35% to 75% of the individuals of Saguaro in various stands on the south slope of the Catalinas were killed. Mortality in Barrel Cactus in the same area was also high. Damage was also reported to *Cereus thurberi*, *C. schottii*, *C. giganteus*, *Bursera microphylla* and other cacti and sub-tropical shrubs at Organ Pipe Cactus National Monument. **Source:** Niering et al., 1963; Lowe, 1964; Steenbergh and Lowe, 1976b.

January, 1971. Minimum Temperature: 11°F at Campbell Avenue Farm in Tucson, 20°F at Tucson International Airport. **Duration:** 18 hours at Tucson International Airport. **Observations of Damage to Plants:** High mortality of seedling and juvenile Saguaro was observed in Saguaro National Monument East, and *Cercidium microphyllum* and *Ferocactus wislizenii* were killed. Die-back and complete kill of *Olneya tesota* was seen in the Tucson Mountains. At Organ Pipe Cactus National Monument, both *Cereus thurberi* and *C. schottii* were damaged and "a substantial number of individuals" were killed. Near Guaymas, Sonora *Ficus palmeri* was injured. Both *Ipomaea arborescens* and *Lysiloma watsoni* suffered leaf and twig damage in the vicinity of Hermosillo, Sonora. **Source:** Steenbergh and Lowe, 1976a, 1977; Jones, 1979.

December, 1978. Minimum Temperature: 15°F at Campbell Avenue Farm in Tucson, 21°F at Arizona-Sonora Desert Museum, 21°F at Organ Pipe Cactus National Monument. **Duration:** 18 hours at Tucson International Airport. **Observations of Damage to Plants:** The following species were frozen to the ground at the Arizona-Sonora Desert Museum: *Hyptis emoryi*, *Tecoma stans*, *Beloperone californica*, *Ambrosia ambrosioides*, *Bursera microphylla*. At Organ Pipe Cactus National Monument *Jatropha cinerea*, *J. cardiophylla*, *J. cuneata*, *Bursera microphylla* and *Encelia farinosa* were frozen to the ground. *Olneya tesota*, *Coursetia microphylla*, *Beloperone californica* and *Sapium biloculare* were damaged. *Encelia farinosa* and *Lysiloma watsoni* were severely damaged in Palm Canyon near Magdalena, Sonora. *Bursera fragilis*, *Cereus thurberi* and *Erythrina flabelliformis* were also damaged. **Source:** Anonymous, 1979; Jones, 1979; personal observation.

Literature Cited

Anonymous. 1979. The severe freeze of 1978-79 in the Southwestern United States. *Desert Plants* 1: 37-39.

Cooke, R. U. and R. W. Reeves. 1976. *Arroyos and Environmental Change in the American Southwest*. Clarendon Press. Oxford.

Felger, R. S. and C. H. Lowe. 1967. Clinal variation in the surface-volume relationships of the columnar cactus

Lophocereus schottii in northwestern Mexico. *Ecology* 48: 530-536.

- Hastings, J. R. 1963. *Historical Change in the Vegetation of a Desert Region*. Ph.D. Dissertation. University of Arizona. Tucson.
- Hastings, J. R. and R. M. Turner. 1965. *The Changing Mile*. University of Arizona Press. Tucson.
- Jones, W. 1979. Effects of the 1978 freeze on native plants of Sonora, Mexico. *Desert Plants* 1:33-36.
- Leopold, L. B. 1951. Rainfall frequency: an aspect of climatic variation. *Transact. Amer. Geophys. Union* 32: 347-357.
- Lowe, C. H. 1964. *Arizona's Natural Environment*. University of Arizona Press. Tucson.
- Niering, W. A., R. H. Whittaker and C. H. Lowe. 1963. The Saguaro: a population in relation to environment. *Science* 142: 15-23.
- Shreve, F. 1910. The rate of establishment of giant cactus. *Plant World* 13: 235-240.
- Shreve, F. 1911. The influence of low temperatures on the distribution of the giant cactus. *Plant World* 14: 136-146.
- Shreve, F. 1912. Cold air drainage. *Plant World* 15: 110-115.
- Shreve, F. 1914. The role of winter temperatures in determining the distribution of plants. *Amer. J. Bot.* 1: 194-202.
- Steenbergh, W. F. and C. H. Lowe. 1976a. Ecology of the Saguaro: I. The role of freezing weather in a warm-desert population. pp. 49-92, in *Research in the Parks*. National Park Service Symp. Ser. 1. Government Printing Office. Washington, D.C.
- Steenbergh, W. F. and C. H. Lowe. 1976b. The Saguaro giant cactus: an ecological perspective. pp. 71-78, in *Proceedings of the First Conference on Scientific Research in the National Parks*. Vol. I. National Park Service Transactions and Proceedings Series No. 5.
- Steenbergh, W. F. and C. H. Lowe. 1977. *Ecology of the Saguaro: II. Reproduction, Germination, Establishment and Survival of the Young Plant*. National Park Service Scientific Monograph Series No. 8. Government Printing Office. Washington, D.C.
- Thornber, J. J. 1916. Introduction. pp. 119-122, in J. C. T. Uphof. *Cold Resistance in Spineless Cacti*. University of Arizona Agricultural Experiment Station Bulletin No. 79.
- Turnage, W. V. and A. K. Hinckley. 1938. Freezing weather in relation to plant distribution in the Sonoran Desert. *Ecol. Monogr.* 8: 530-550.
- U.S. Weather Bureau. 1894-1979. *Climatological Data Summaries, Arizona*.
- Wiggins, I. L. 1937. Effects of the January freeze upon the Pitahaya in Arizona. *Cact. & Succ. Soc. J.* 8: 171.