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Correlation of Climatic Factors and Occurrence of *Puccinia grindeliae* on Herbarium Specimens of *Gutierrezia* spp. Collected in Southwestern States Since 1891.

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Broom snakeweed (*Gutierrezia sarothrae* [Pursh] Britton and Rusby) is a weedy, half-shrub native to the rangelands of the western United States, Mexico, and Canada (Lane, 1985). *Gutierrezia sarothrae* and related species have been spreading throughout southwestern rangelands over the past 100 years in response to environmental and human factors (McDaniel, Pieper, and Donart, 1982). Broom snakeweed is toxic to cattle and responsible for poor forage production (Heitschmidt, 1979; McDaniel *et al.*, 1982; Nabado, Pieper, and Beck, 1980). We are evaluating the potential of *Puccinia grindeliae* Peck to act as a biological control agent of *Gutierrezia* spp. in the southwestern U.S.

We chose *Puccinia grindeliae* for this study because it is a member of a genus of plant pathogenic fungi that contains some of the most devastating known pathogens of plants and it attacks only broom snakeweed and closely related plants. *Puccinia* Persoon. species, many of which cause significant economic losses annually on crops throughout the world, are rust pathogens of virtually all higher plants (Cummins and Hiratsuka, 1983). *Puccinia* species are

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basidiomycetes, are therefore related to mushrooms and, in common with mushrooms, produce basidia and basidiospores. There are 3,000 to 4,000 different species of *Puccinia*, all showing a remarkable degree of host specificity. Most species of *Puccinia* attack only one or two plant genera and in some cases may attack only a few varieties of one plant species. This means they are potentially ideal biological control agents, being both devastating pathogens that are highly selective and highly damaging to target weeds but not to nontarget plants. *Puccinia* species often do not kill their hosts, but reduce photosynthesis dramatically by destroying leaf tissue and eliminating flowering and fruit production very effectively (fig. 1a).

Rust fungi such as *Puccinia* are obligate pathogens of living land plants and get their name from the rusty yellow or orange color of the spore pustules on green plant tissue. Many species of *Puccinia* produce up to five distinct spore stages, and many require two unrelated groups of host plants in order to complete their life cycle (heteroecious life cycle). However, several species such as *P. grindeliae* produce only two spore stages and complete their life cycle on only one host (autoecious life cycle). *Puccinia grindeliae* produces only basidiospores and teliospores and completes its entire life cycle on *Gutierrezia* species and about 20 other closely related genera of weedy plants (Cummins, 1978). The basidiospores are the infectious spore stage, and the teliospores are dark, thick-walled overseasoning spores that occur in small black pustules called “telia” on leaves and photosynthetic stems. Occasionally, we have observed other spore stages, such as aeciospores and the rust-colored urediniospores, but these spore stages do not appear to be common in the field, and we do not believe they play an important role in the epidemiology of snakeweed rust caused by *P. grindeliae*.

In epidemiological studies on *P. grindeliae* (Liddell, Waddell, and McEntee, 1993), we found the examination of dried herbarium specimens of *Gutierrezia* spp. provided a good source of information on the historical distribution of *P. grindeliae*. This bulletin reports on the use of dried herbarium specimens to determine the historical distribution patterns of *P. grindeliae*, as part of a major project to determine the long-term potential of *P. grindeliae* as a biocontrol agent of broom snakeweed in the southwestern U.S.

Fig. 1a. Herbarium specimen #567 from Nara Visa, NM, collected in 1907.

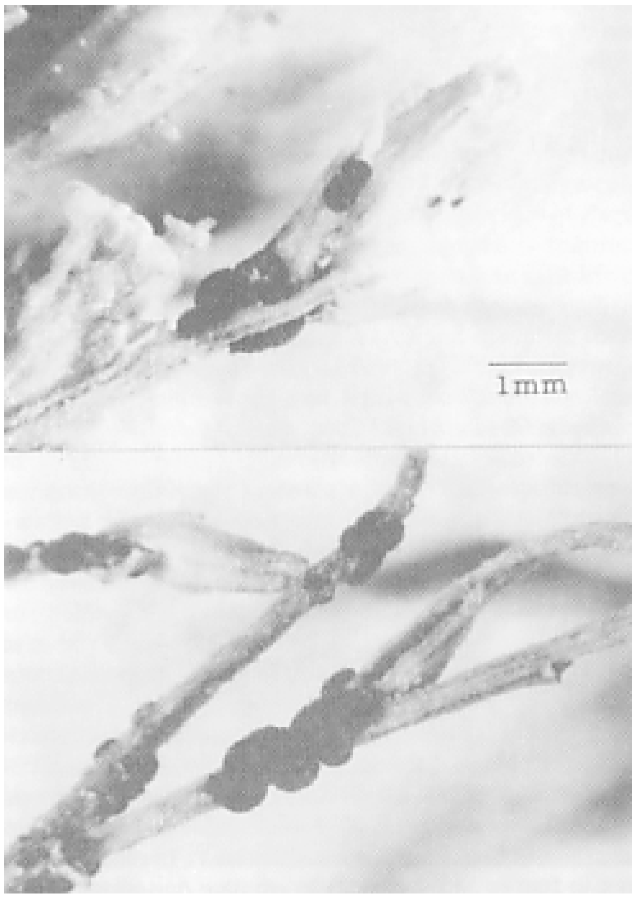

Fig. 1b. Close-up of *Puccinia grindeliae* on specimen #567.

Herbarium collections are a valuable resource for historical investigations into pathogens of non-crop plants such as *Gutierrezia*. First, it is easy to examine a large number of sites quickly and efficiently, covering a wider area than can be readily visited. Second, some collections represent sites that are no longer accessible or existent. Third and most important, dried herbarium specimens provide the only source of historical information on diseases of rangeland weeds, due to an almost complete lack of published information on these pathogens.

P. grindeliae was first described in Colorado on *Grindeliae squarrosa* Pursh (Dunal) in 1879 (Peck, 1879). Most of the information about diseases and pathogens of rangeland weeds, such as *Gutierrezia*, is contained only in descriptive reports and floras. *P. grindeliae* has been reported in just 14 publications since 1918 (Brenckle, 1918; Cummins, 1979; Farr, Bills, Chamuris, and Rossman, 1989; Gilbertson and McHenry, 1969; Solheim, 1934, 1940, 1943, 1954; Solheim and Cummins, 1957, 1959, 1970a, 1970b, 1979; Yohem, Cummins, and Gilbertson, 1985). The scant epidemiological and ecological data available on *P. grindeliae* is found only in detailed floras, such as Cummins (1978). There are certainly no reports on the distribution of this pathogen in the first half of this century, and virtually nothing is known about its occurrence. This lack of information on diseases and pathogens of rangeland weeds is due to their low economic importance, coupled with the nature of the habitats where these plants occur.

The objectives of our study are: 1) to provide some rudimentary information on the occurrence of *P. grindeliae* over the past 100 years; 2) to determine the longevity of *P. grindeliae* at specific sites in New Mexico and Arizona; 3) to correlate rust collections with climate records; and 4) to evaluate the correlation of herbarium collections with occurrence in the field and mortality of snakeweed over the past 100 years.

PROCEDURES

Herbarium Collections

Dried herbarium specimens of 11 species of *Gutierrezia* at nine university herbaria in Arizona, New Mexico, and Texas (table 1) were examined microscopically for telia of *P. grindeliae*. The study comprised a total of 1,048 herbarium specimens of *Gutierrezia* spp. collected throughout the southwestern U.S. from 1891 to 1991. Most of these specimens were collected in North America, and all identities were confirmed by Meredith Lane (Lane, 1982, 1983, 1985) (table 1). Seven additional specimens of *P. grindeliae*, on *G. sarothrae* and *G. californica*, were also examined at the University of Arizona Mycology Herbarium (table 1). All herbarium specimens examined were originally assigned to 24 species of *Gutierrezia*, which were reduced to synonymy with 11 species based on a recent taxonomic revision (Lane, 1985). Accepted species included in our study are listed in table 2.

Survey of Herbarium Specimens

Herbarium specimens were examined in a systematic fashion by looking quickly for evidence of *Puccinia grindeliae* telia on leaves and stems. If no obvious telia were found the specimen was examined closely using a 10x lens for 5 minutes. All telia were confirmed to be *P. grindeliae* by removing a small number of teliospores from each specimen for microscopic observation. Annotations were made on all specimens where the presence of *P. grindeliae* was confirmed. The location of each collection and date of collection was noted for each specimen, and each location was mapped as accurately as annotations on the herbarium sheet would allow.

Analysis of Historical Weather Data

All specimens from herbaria, except the seven collections of *P. grindeliae* from the University of Arizona Mycology Herbarium, were mapped to obtain elevation, latitude, and longitude and to locate the nearest weather stations for precipitation and temperature data (table 3). Weather data were obtained from the

Table 1. Herbarium collections examined for the occurrence of *Puccinia grindeliae* telia on *Gutierrezia* spp.

Herbarium	Number of specimens examined	Number of specimens bearing telia of *P. grindeliae*
New Mexico State University		
Biological Science	162	14
Range Science	25	2
University of New Mexico		
Biology	238	4
Texas A & M University		
Range Science	241	4
University of Texas at Austin		
Botany	252	9
University of Texas at El Paso		
Biology	36	1
Texas Tech University		
Range Science	36	0
University of Arizona		
Biological Sciences	58	5
Sub-Total	1048	39
University of Arizona		
Mycology[a]	7	7
Total	1055	46

[a]Herbarium collections of *P. grindeliae*

Table 2. Species of *Gutierrezia* herbarium and field survey specimens examined for the presence of *Puccinia grindeliae*.

Species	Number of herbarium specimens examined	Number of herbarium specimens bearing telia of *P. grindeliae*	Number of field survey specimens examined	Number of field survey specimens bearing telia of *P. grindeliae*
Gutierrezia Lagasca spp.	11	0	0	0
G. alamanii A. Gray	2	0	0	0
G. californica (D.C) Torrey & A. Gray	10	3[a]	0	0
G. conoidea (Hemsley) M.A. Lane	2	0	0	0
G. grandis S.F. Blake	2	0	0	0
G. mandonii (Sch. Bip.) Solbrig	10	0	0	0
G. microcephala (D.C) A. Gray	201	4	0	0
G. sarothrae (Prush) Britton & Rusby	652	35[b]	35	20
G. serotina E. Greene	7	1	0	0
G. sphaerocephala A. Gray	82	2	0	0
G. texana (D.C) Torrey & A. Gray	58	1	0	0
G. wrightii A. Gray	18	0	0	0

[a]These three specimens of *Puccinia grindeliae* were from the University of Arizona mycological herbarium
[b]Includes four specimens of *Puccinia grindeliae* from the University of Arizona mycological herbarium

Table 3. Specimens used for logistic regression analysis.

Specimen #	Rust +/-	Species	County	Date	Weather station	Distance from weather station (km)	Elevation of site (m)	Elevation of weather station (m)
81	+	*G. sarothrae*	Otero	09 Aug 39	Mescalero	18.6	2092	2020
670	-	*G. sarothrae*	Otero	14 Sep 60	Mescalero	9.3	2234	2020
121	+	*G. sarothrae*	Otero	08 Sep 39	Mescalero	18.6	2092	2020
795	-	*G. sarothrae*	Otero	05 Sep 71	Mescalero	3.5	2084	2020
518	+	*G. microcephala*	Lincoln	07 Oct 07	Ft. Stanton	34.8	1966	1900
698	-	*G. sarothrae*	Lincoln	09 Oct 71	Ft. Stanton	32.5	1755	1900
519	+	*G. microcephala*	Quay	18 Sep 07	Tucumcari	55.7	1167	1280
300	-	*G. sarothrae*	Quay	26 Sep 64	Tucumcari	18.6	1210	1280
529	+	*G. sarothrae*	Doña Ana	28 Oct 06	Mesilla Pk	23.2	1314	1067
591	-	*G. sphaerocephala*	Doña Ana	16 Sep 03	Mesilla Pk	23.2	1309	1067
547	+	*G. sarothrae*	Quay	19 Oct 07	Tucumcari	23.2	1321	1280
531	-	*G. sarothrae*	Quay	24 Sep 07	Tucumcari	1.2	1247	1280
550	+	*G. sarothrae*	San Miguel	28 Sep 07	Las Vegas	1.2	1981	1951
845	-	*G. microcephala*	San Miguel	24 Jul 63	Las Vegas	41.8	2300	1951
557	+	*G. sarothrae*	Colfax	22 Sep 07	Springer	1.6	1768	1786
307	-	*G. sarothrae*	Colfax	05 Aug 44	Springer	1.6	1771	1786
561	+	*G. sarothrae*	De Baca	11 Oct 07	Portales	78.9	1253	1220
571	-	*G. sarothrae*	De Baca	28 Aug 73	Ft. Sumner	11.6	1311	1207
565	+	*G. sarothrae*	Bernalillo	* 1936	Albuquerque	23.2	1806	1585
657	-	*G. sarothrae*	Bernalillo	11 Sep 64	Albuquerque	27.8	2012	1585
587	+	*G. sphaerocephala*	Sierra	20 Sep 07	Hillsboro	23.2	1615	1593
303	-	*G. sarothrae*	Luna	06 Sep 39	Deming	27.8	1448	1319

Table 3. (Cont.)

Specimen #	Rust +/-	Species	County	Date	Weather station	Distance from weather station (km)	Elevation of site (m)	Elevation of weather station (m)
689	+	*G. sarothrae*	Otero	02 Sep 52	Ruidoso	21.0	2042	2096
671	-	*G. sarothrae*	Otero	10 Oct 71	Ruidoso	19.5	2164	2096
918	+	*G. sarothrae*	Guadelupe	15 Sep 35	Santa Rosa	2.4	1448	1410
294	-	*G. sarothrae*	Guadelupe	03 Sep 29	Santa Rosa	1.6	1394	1410
937	+	*G. sarothrae*	Otero	15 Aug 38	Alamogordo	9.3	2235	1311
243	-	*G. sarothrae*	Otero	09 Oct 16	Alamogordo	18.6	1341	1311
723	+	*G. sarothrae*	Sandoval	25 Sep 31	Santa Fe	32.5	1608	2134
820	-	*G. sarothrae*	Sandoval	08 Jun 75	Santa Fe	27.8	1676	2134
759	+	*G. sarothrae*	Mora	01 Sep 76	Springer	51.0	2396	1786
926	-	*G. sarothrae*	Colfax	08 Sep 32	Springer	11.7	1829	1786
567	+	*G. sarothrae*	Quay	02 Oct 07	Nara Visa	1.6	1265	1279
554	-	*G. sarothrae*	Union	09 Oct 07	Albert	37.1	1681	1433
546	+	*G. sarothrae*	Quay	21 Oct 07	Tucumcari	1.6	1244	1280
531	-	*G. sarothrae*	Quay	24 Sep 07	Tucumcari	1.6	1247	1280
555	+	*G. sarothrae*	Santa Fe	28 Sep 07	Santa Fe	27.8	1859	2134
646	-	*G. sarothrae*	Santa Fe	01 Oct 32	Santa Fe	2.4	2179	2134
570	+	*G. sarothrae*	Lincoln	03 Oct 07	Ft. Stanton	32.5	1966	1900
588	-	*G. sphaerocephala*	Lincoln	23 Jul 73	Carrizozo	27.8	2012	1658
683	+	*G. sarothrae*	Mora	01 Aug 76	Ocate	9.3	2396	2198
954	-	*G. sarothrae*	Taos	10 Aug 66	Taos	25.6	2258	2129
1071	+	*G. sarothrae*	Lincoln	03 Aug 80	Capitan	9.0	1905	1935
709	-	*G. sarothrae*	Lincoln	01 Oct 71	Ft. Stanton	15.0	2128	1900
1078	+	*G. microcephala*	Lincoln	02 Oct 83	Capitan	51.0	1496	1935
805	-	*G. sarothrae*	Lincoln	01 Aug 49	Capitan	11.7	2012	1935

* Specimen #565 was collected in the summer of 1936 according to the original herbarium data sheet.

National Oceanic and Atmospheric Administration, National Climatic Center (1905–1991); Williams and McAllister (1981); and Williams (1986). Elevation data were obtained from the herbarium sheets or from high-resolution topographic maps. Due to poor annotation on herbarium sheets and the paucity of good historic weather data, only 46 sites (23 paired sites) could be used in this analysis (table 3).

The relationship between observing rust on herbarium specimens and weather data at the date of specimen collection was analyzed using logistic regression (SAS Institute, 1989). The dependent variable was the score for presence of rust (+ or -), based on paired specimens collected at the same or nearby sites in different years. The independent variables were quarterly rainfall totals and mean daily temperatures for the 12 quarters preceding the date of collection.

Because *P. grindeliae* is an obligate pathogen, conditions that favor the host may be expected to favor the pathogen. Heitschmidt (1979) showed the relative abundance of *Gutierrezia* spp. in Texas was correlated with average daily maximum temperature in April and precipitation in May for the year of collection. Therefore, logistic regression models using monthly rainfall and monthly maximum temperatures for each of the 12 months preceding the date of collection were fitted to determine whether rust observation on herbarium specimens correlated with Heitschmidt's model for *Gutierrezia* occurrence.

The basic assumption in these analyses was that the probability of collecting a rusted plant was directly proportional to the number of rusted plants in the collection area. Only data from herbarium collections of *Gutierrezia* spp. (table 1) were used in this analysis to ensure random sampling of rust occurrence. All rusted and non-rusted herbarium specimens used in the logistic regression analysis except one (specimen 820: table 4) were collected in autumn between the months of August and October. Specimen 820 was collected in the spring (April 8, 1975).

Collections made during the 1990–1993 field survey and held in the NMSU Plant Pathology Herbarium (table 4), and specimens of *P. grindeliae* in the Mycology Herbarium at the University of Arizona (table 1) were excluded from the logistic regression analysis.

Table 4. Specimens cited and their origins.

ID #	Herbarium	Herbarium #	Species	Specific location
81	TAMU	39232	*G. sarothrae*	3 miles SW of Ruidoso Jct., Lincoln Co. NM
121	TAMU	39169	*G. sarothrae*	3 miles SW of Ruidoso Jct., Lincoln Co. NM
243	UTA	NA	*G. sarothrae*	South of Dog Canyon, Otero Co. NM
294	UTA	147577	*G. sarothrae*	Santa Rosa, Guadalupe Co. NM
300	UTA	233494	*G. sarothrae*	15 miles E of Tucumcari, Quay Co. NM
302	UTA	147558	*G. sarothrae*	20 miles SW of Clayton, Union Co. NM
303	UTA	NA	*G. sarothrae*	21 miles NW of Deming, Luna Co. NM
307	UTA	147715	*G. sarothrae*	1/2 mile E of Springer, Colfax Co. NM
518	NMSUBIO	30382	*G. sarothrae*	White Oaks, Lincoln Co. NM
519	NMSUBIO	30384	*G. microcephala*	Endee, Quay Co. NM
529	NMSUBIO	39007	*G. sarothrae*	Plains near Doña Ana Mountains, Doña Ana Co. NM
531	NMSUBIO	30443	*G. sarothrae*	Tucumcari, Quay Co. NM
546	NMSUBIO	30385a	*G. sarothrae*	Ogle, Quay Co. NM
547	NMSUBIO	30385b	*G. sarothrae*	Tucumcari, Quay Co. NM
550	NMSUBIO	39058	*G. sarothrae*	E. of Las Vegas, San Miguel Co. NM
554	NMSUBIO	30426	*G. sarothrae*	Beenham, Union Co. NM
557	NMSUBIO	30425	*G. sarothrae*	Springer, Colfax Co. NM
561	NMSUBIO	30418	*G. sarothrae*	La Lande, De Baca Co. NM
565	NMSUBIO	USDA	*G. sarothrae*	Mesa E. of Albuquerque, Bernalillo Co. NM
567	NMSUBIO	30362	*G. sarothrae*	Nara Visa, Quay Co. NM
570	NMSUBIO	30383	*G. sarothrae*	White Oaks, Lincoln Co. NM
571	NMSUBIO	7436	*G. sarothrae*	9 miles NNE of Ft. Sumner T.4 N, R.26.E, sec. 3, De Baca Co. NM
587	NMSUBIO	30402	*G. sphaerocephala*	Lake Valley, Sierra Co. NM
588	NMSUBIO	43782	*G. sphaerocephala*	6 miles NW of Jicarilla and 1/4 mile S. of Ancho, Lincoln Co. NM
591	NMSUBIO	30403	*G. sphaerocephala*	Lake E. of Doña Ana Mts., Doña Ana Co. NM

Table 4. Specimens cited and their origins. (cont.)

ID #	Herbarium	Herbarium #	Species	Specific location
594	NMSUBIO	30409	*G. sphaerocephala*	Mesa near Las Cruces, Doña Ana Co. NM
646	UNM	1842	*G. sarothrae*	Road side near Santa Fe, Santa Fe Co. NM
657	UNM	43424	*G. sarothrae*	Embudo Canyon, Sandia Mt., Cibola Nat. For. NE 1/4 S.3, T.10 N, R.4 E, Bernalillo Co. NM
670	UNM	23972	*G. sarothrae*	6 miles NE of Mescalero Rt. 70 in a valley, Otero Co. NM
671	UNM	51451	*G. sarothrae*	Hwy. 70 1 mile east of Mescalero, Otero Co. NM
683	UNM	68982	*G. sarothrae*	Les Felris canyon, N. car camp area of Lazy 3 Ranch, 7 miles W. of Ocata, Mora Co. NM
689	UNM	68982	*G. sarothrae*	Roadside Mescalero, Otero Co. NM
698	UNM	51185	*G. sarothrae*	Roadside Hwy. 380 4 miles E. of Carrizozo, Lincoln Co. NM
709	UNM	51195	*G. sarothrae*	Roadside Hwy. 37 1 mile N. of Angus, Lincoln Co. NM
723	UNM	941	*G. sarothrae*	Roadside near Domingo, Sandoval Co. NM
759	UNM	59607	*G. sarothrae*	Les Felris canyon, N. car camp area of Lazy 3 Ranch, 7 miles W. of Ocata, Mora Co. NM
769	UNM	29223	*G. sarothrae*	Near Stallion site on US 380, Socorro Co. NM
795	UNM	51493	*G. sarothrae*	Roadside Hwy. 70 15 miles W. of Ruidoso, Otero Co. NM
805	UNM	10405	*G. sarothrae*	0.6 miles S. of Nogal, Lincoln Co. NM
820	UNM	57196	*G. sarothrae*	Cochiti Lake at the Jct. of Blend Canyon and Rio Grande, Sandoval Co. NM
845	UNM	67814	*G. microcephala*	S. of Glorieta Mesa SS T.13N, R.13E, San Miguel Co. NM
883	NMSUEPWS	EP0001	*G. sarothrae*	Alter rd. off Sasabe rd., AZ Hwy. 286 W. of Tuson, Pima Co. AZ
884	NMSUEPWS	EP0002	*G. sarothrae*	Buenas Aires Ranch N. of Sasabe, AZ, Pima Co. AZ
885	NMSUEPWS	EP0003	*G. sarothrae*	Buenas Aires Ranch N. of Sasabe, AZ, Pima Co. AZ
886	NMSUEPWS	EP0004	*G. sarothrae*	Buenas Aires Ranch N. of Sasabe, AZ, Pima Co. AZ
887	NMSUEPWS	EP0005	*G. sarothrae*	Youngblood Ranch near cattle pond 1, west road, Socorro Co. NM
888	NMSUEPWS	EP0006	*G. sarothrae*	Youngblood Ranch near fence, Socorro Co. NM

Table 4. Specimens cited and their origins. (cont.)

ID #	Herbrrium	Herbarium #	Species	Specific location
889	NMSUEPWS	EP0007	*G. sarothrae*	Las Cruces Airport, Doña Ana Co. NM
890	NMSUEPWS	EP0008	*G. sarothrae*	Jornada Exp. Range South windmill, Doña Ana Co. NM
891	NMSUEPWS	EP0009	*G. sarothrae*	Jornada Exp. Range South windmill, Doña Ana Co. NM
892	NMSUEPWS	EP0081	*G. sarothrae*	Jct. 22 Santo Domingo Hwy., Sandoval Co. NM
893	NMSUEPWS	EP0082	*G. sarothrae*	Nara Visa, Quay Co. NM
897	NMSUEPWS	EP0016	*G. sarothrae*	1/10 of a mile S. of Tucson, AZ, Pima Co. AZ.
898	NMSUEPWS	EP0017	*G. sarothrae*	N. of Lovington E of the power plant, Hidalgo Co. NM
899	NMSUEPWS	EP0018	*G. sarothrae*	Rd to Hachita, AZ mile marker 15, Pima Co. AZ
900	NMSUEPWS	EP0019	*G. sarothrae*	Youngblood Ranch, Socorro Co. NM
901	NMSUEPWS	EP0020	*G. sarothrae*	Youngblood Ranch, Socorro Co. NM
902	NMSUEPWS	EP0021	*G. sarothrae*	Rt. 380 7/10 mile E. of mile marker 180, Chavez Co. NM
903	NMSUEPWS	EP0022	*G. sarothrae*	Rt. 380 7/10 mile E. of mile marker 180, Chavez Co. NM
904	NMSUEPWS	EP0023	*G. sarothrae*	15–16 mile NE of San Antonio @ gate of Youngblood Ranch, Socorro Co. NM
905	NMSUEPWS	EP0024	*G. sarothrae*	Youngblood Ranch, Socorro Co. NM
906	NMSUEPWS	EP0025	*G. sarothrae*	S. of Deming 5.2 miles E. of Rockhound St. Park access rd. S. side of rd., Luna Co. NM
907	NMSUEPWS	EP0026	*G. sarothrae*	S. of Deming 5.2 miles E. of Rockhound St. Park access rd. S. side of rd., Luna Co. NM
908	NMSUEPWS	EP0027	*G. sarothrae*	S. of Deming 5.2 miles E. of Rockhound St. Park access rd. S. side of rd., Luna Co. NM
909	NMSUEPWS	EP0028	*G. sarothrae*	S. of Deming 5.2 miles E. of Rockhound St. Park access rd. S. side of rd., Luna Co. NM
910	NMSUEPWS	EP0029	*G. sarothrae*	NE of Deming on US 180 (15.2 miles from I-10) W. side of rd.
918	UABIO		*G. sarothrae*	Santa Rosa, Tucumcari Hwy., Guadalupe Co. NM
926	UABIO	138281	*G. sarothrae*	Roadside 8 miles S. of Springer, Colfax Co. NM

Table 4. Specimens cited and their origins. (cont.)

ID #	Herbarium	Herbarium #	Species	Specific location
937	UABIO	105609	*G. sarothrae*	Head of Dry Canyon, Otero Co. NM
949	UABIO	181084	*G. sarothrae*	Jornada Exp. Range, 17 miles N. of Las Cruces, Doña Ana Co. NM
954	UABIO	174552	*G. sarothrae*	Near Picurio Pueblo in valley of Rio Pueblo, Taos Co. NM
963	UABIO	102635	*G. sphaerocephala*	Ranch 23 miles N. of Las Cruces, Doña Ana Co. NM
1069	NMSURS	W#7	*G. microcephala*	1/4 mile E. of A Mountain in Las Cruces, Doña Ana Co. NM
1071	NMSURS	LE299	*G. sarothrae*	Fort Stanton, short duration pasture, Lincoln Co. NM
1078	NMSURS	LO402	*G. microcephala*	R 19 E, T 75, sec 29, NW1/4 of NW1/4 4.6 miles W. Middle Arroyo Ranch Road on NM 48, Lincoln Co. NM
1093	NMSUEPWS	EP0083	*G. sarothrae*	Forest rd. 90, Lincoln Nat. Forest, W side of road about 3 1/2 miles from NM Hwy. 82, Otero Co. NM
1094	NMSUEPWS	EP0084	*G. sarothrae*	2.8 miles from corner of 4th and Maxwell, E. of Springer N. side Rt. 56, Colfax Co. NM
1095	NMSUEPWS	EP0086	*G. sarothrae*	Mile marker 259 N side of the Hwy. 2 miles from Ruidoso Jct., Lincoln Co. NM
1096	NMSUEPWS	EP0087	*G. sarothrae*	Point of interest Mescalero, Otero Co. NM

Key to Herbaria
NMSUBIO: New Mexico State University—Biology Herbarium
NMSUEPWS: New Mexico State University—Plant Pathology Herbarium
NMSURS: New Mexico State University—Range Science Herbarium
TAMU: Texas A&M University—Range Science Herbarium
UABIO: University of Arizona—Bbiological Sciences Herbarium
UNM: University of New Mexico—Biology Herbarium
UTA: University of Texas at Austin—Botany Herbarium

Field Survey

A series of field surveys of *Gutierrezia* species conducted from 1990 to 1993 had two primary objectives. First, sites represented by rusted herbarium specimens that could be located accurately from annotations on the herbarium sheet were visited to determine the current status of the host and pathogen. Second, random surveys were conducted to determine, as fully as possible, the extant distribution of *Puccinia grindeliae* in New Mexico.

Only 13 collection sites of rusted herbarium specimens of *G. sarothrae* from New Mexico could be located accurately from annotations on the herbarium sheets. These were revisited in 1990–1993 (table 5). Only one non-rusted herbarium collection was located accurately and revisited (table 5). Because it is impossible to determine population densities of hosts and pathogens from herbarium specimens, this aspect of the survey was designed to gather data only on the presence or absence of the host and pathogen presently at each site.

Random surveys were conducted throughout New Mexico by driving along roads in 20 of 33 counties and stopping to examine all major communities of *G. sarothrae* for the presence of *P. grindeliae*. At least 200 individual *G. sarothrae* communities were examined in the random survey. The survey procedure was the same for both surveys. At each site the observer walked straight toward the middle of the *G. sarothrae* community for 100 meters and then curved back to the road along a wide arc. Every 20 meters, the observer closely examined a small number of potentially rusted plants for 5 minutes. At each site, the observer examined no fewer than 10 plants for telia of *P. grindeliae* before moving on to a new site.

Preliminary identification of *P. grindeliae* was made in the field. Collections were transported to the laboratory in paper bags and plant presses for confirmation of both host and pathogen identities and permanent mounting.

Table 5. Herbarium specimen collection sites revisited during the field survey.

Herbarium specimen ID #	Revisitation class[a]	Collection date	Rust presence	Survey specimen ID #	Collection date	Rust presence
81	I	8 Sep 07	+	1095	8 Oct 93	+
121	I	8 Sep 07	+	1095	8 Oct 93	+
302	II	NA	+		1 Jul 91	-
550	II	28 Sep 07	+		4 Jul 91	-
555	II	28 Sep 07	+		4 Jul 91	-
557	II	22 Sep 07	+	1094	29 Jul 93	+
567	II	2 Oct 07	+	889	15 Jul 91	+
689	II	2 Sep 52	+	1096	8 Oct 93	+
723	II	25 Sep 31	+	892	3 Jul 91	+
769	I	19 Sep 61	-	887	20 Apr 90	+
937	II	15 Aug 38	+	1093	6 Jul 93	+
1071	II	3 Aug 80	+		10 Oct 93	-
1078	I	2 Oct 83	+		10 Oct 93	-

[a] Revisitation class I—excellent annotation on herbariums sheet allowing location of original collection site to within 500 meters;

Revisitation class II—reasonable annotation on herbarium sheets allowing location of original collection site to within 2–3 km.

RESULTS

Survey of Herbarium Specimens

Overall, 3.7% of 1,048 *Gutierrezia* spp. herbarium specimens were rust positive (table 1). The oldest specimen was collected in 1891 and the earliest rusted specimen was from the Jornada Experimental Range near Las Cruces, NM, in 1906 (specimen 529). The condition of these old specimens was generally very good. Of 488 specimens examined from New Mexico, 24 were rust positive: 12 between 1891 and 1910, none between 1910 and 1930, six between 1931 and 1950, one between 1951 and 1970, four between 1971 and 1990; one rust-positive collection was not dated. Based on these observations, 4.9% of herbarium specimens collected in New Mexico between 1891 and 1990 were rusted (table 6). The 24 diseased herbarium specimens collected from New Mexico were found in 14 counties ranging in elevation from 1100 m to 2500 m located east of the Rio Grande (fig. 2).

Of the 119 herbarium specimens from Arizona, 5 were rust positive: one between 1911 and 1930, two between 1931 and 1950, and two between 1971 and 1990. Based on these specimens, 4.2% of plants collected in Arizona from 1911 to 1990 were diseased.

Of the seven specimens of *P. grindeliae* held at the University of Arizona Mycology Herbarium, five were collected in Arizona, and two were collected in Colorado and Wyoming. Overall, the ten diseased specimens from Arizona were collected from seven counties spanning the state from north to south at elevations ranging from 750 m to 2100 m (fig. 2). Diseased herbarium specimens were collected from other parts of the U.S.: California (1 diseased specimen out of 45), Colorado (0/27), Nevada (1/23), Nebraska (1/1), Texas (1/235), Utah (1/39), and Wyoming (1/8) (fig. 3). Four diseased specimens were also collected from Mexico (4/27) (table 6).

Table 6. States in the U.S. and other countries where specimens were collected.

State	Number of herbarium specimens examined	Number of herbarium specimens bearing telia of *P. grindeliae*	Number of field survey specimens examined	Number of field survey specimens bearing telia of *P. grindeliae*
Argentina	10	0	0	0
Canada	3	0	0	0
Saskatchewan	2	0	0	0
Mexico	27	4	0	0
United States	1008	35	35	20
Arizona	119	10[a]	6	0
California	45	1	0	0
Colorado	27	1[b]	0	0
Idaho	5	0	0	0
Kansas	5	0	0	0
Nebraska	1	1	0	0
Nevada	23	1	0	0
New Mexico	488	24	29	20
North Dakota	3	0	0	0
Oklahoma	8	0	0	0
Oregon	1	0	0	0
South Dakota	1	0	0	0
Texas	235	1	0	0
Utah	39	1	0	0
Wyoming	8	2[c]	0	0

[a] Includes five specimens of *P.grindeliae* from the University of Arizona Mycology Herbarium.

[b] This specimen of *P. grindeliae* was from the University of Arizona Mycology Herbarium.

[c] Includes one specimen of *P. grindeliae* from the University of Arizona Mycology Herbarium.

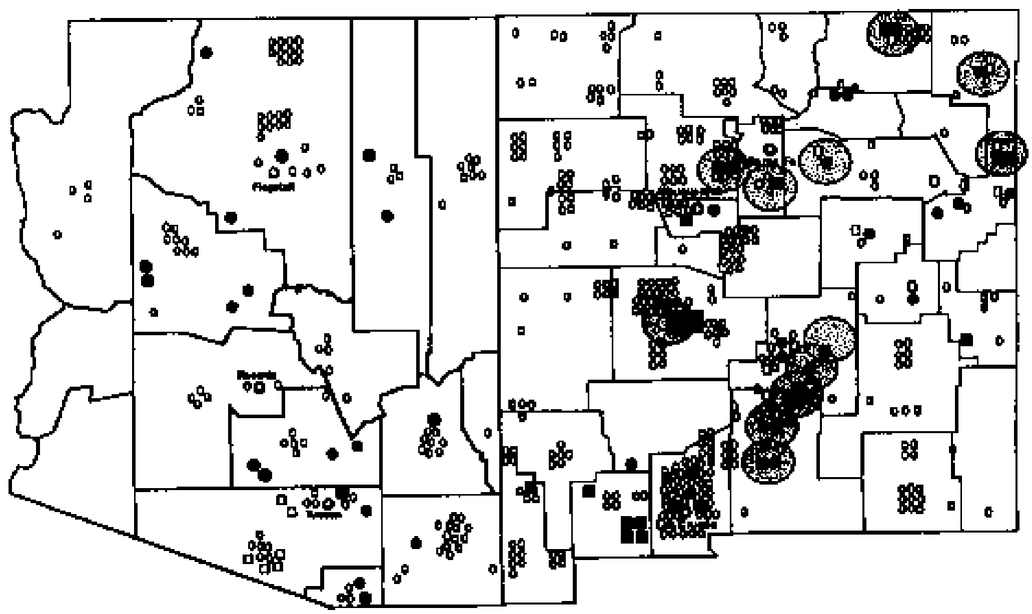

Fig. 2. Map of Arizona and New Mexico showing sites where herbarium specimens diseased with *Puccinia grindeliae* were collected from 1891 to 1990 (●) and sites where the field survey collection of diseased plants were made (■). Collection sites of non-rusted herbarium specimens (❍) and non-rusted field survey specimens (❑) are also shown. The large shaded circles represent sites that were revisited in 1990–1993 (table 5).

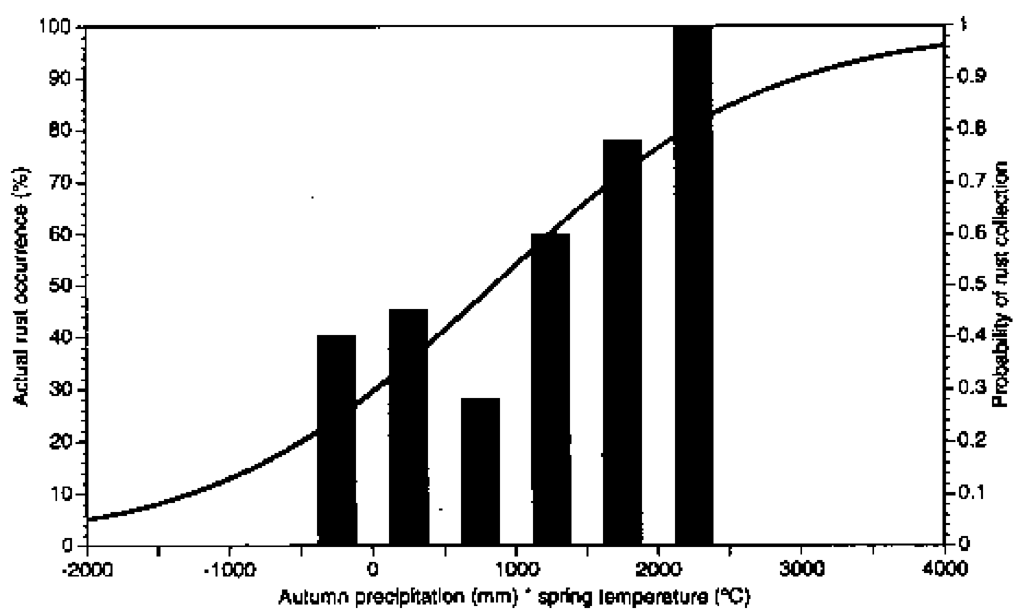

Fig. 3. Plot of the probability of any herbarium specimen being diseased with *Puccinia grindeliae* based on the product of the precipitation (mm) of the fall quarter in which the specimen was collected and the mean daily temperature (°C) of the preceding spring quarter (right axis). Actual percent rust occurrence on herbarium specimens based on 23 paired sites (table 3) is shown as bars (left axis).

Analysis of Historical Weather Data

Logistic analysis of historical weather data showed the probability of collecting a diseased specimen was positively correlated

$$\chi^2_1 = 4.23[p \leq 0.03]$$

with the product of precipitation in the quarter of collection and mean temperature in the preceding spring quarter. The logistic regression equation for the relationship between autumn precipitation (mm) (AUPRECIP), spring temperature (°C) (SPTEMP), and probability of rust occurrence used was:

$$\ln(p/[1-p]) = - 0.8706 + 0.00103*(AUPRECIP*SPTEMP).$$

Solving for p in this equation, the predicted probability (p) of any herbarium specimen being diseased by *P. grindeliae* is:

$$p = (1 + \exp [0.8706 - 0.00103*(AUPRECIP*SPTEMP)])^{-1}.$$

The graph of the predicted probability (p) as given by this equation is shown in fig. 3. This indicates the predicted probability of a herbarium specimen being diseased with *P. grindeliae* is higher in years when both autumn precipitation and spring temperature are high.

Field Survey

In most cases, *Gutierrezia* populations were still abundant at the herbarium collection sites. A few areas have been subject to highway development and roadside burning for many years, and *Gutierrezia* spp. were present in low numbers. Although the herbarium survey of *Gutierrezia* communities in Arizona disclosed 10 rusted specimens, no rusted specimens were found during 1990–93 field surveys. Field surveys of New Mexico communities of *Gutierrezia* yielded 20 rusted and nine non-rusted specimens of *G. sarothrae* collected at elevations from 1100 m to 1800 m. These specimens were permanently mounted for the New Mexico State University Plant Pathology Herbarium and given accession numbers as shown in table 4. In 1990–1993 *Puccinia grindeliae* was

found in only eight of the 13 sites, which were located accurately from annotations on the herbarium sheets. There was only one site where no rust was present on the herbarium specimen,but *P. grindeliae* was present in 1990–1993 (table 5).

Most specimens from both herbarium and survey collections were *G. sarothrae*. *Gutierrezia microcephala* was the second most abundant species collected. Nine other species were represented, with small collection numbers (table 2).

DISCUSSION

Puccinia grindeliae has been present on broom snakeweed in New Mexico and Arizona for at least 88 years and is still present at two sites where *P. grindeliae* was collected in 1906 and 1907: the Jornada Experimental Range near Las Cruces (specimen 529) and Nara Visa in northeastern New Mexico (specimen 567) (fig. 1b). The rust does not appear to have influenced the range and density of the *Gutierrezia* spp. populations in the southwest U.S. significantly over the past 100 years. All sites where the rust was found up to 88 years ago are still populated by *Gutierrezia* species, though at five sites the rust itself could not be found (table 5). *Puccinia grindeliae* was not found west of the Rio Grande in New Mexico prior to 1990, although it was found in eastern Arizona as early as 1905 at Pinal, in the Santa Catalina Mountains. The pathogen apparently expanded into western New Mexico recently, possibly from Arizona and Mexico due to the prevailing southwesterly winds or human activity. The general increase in the density of *Gutierrezia* spp. on New Mexico rangelands over the past 100 years (McDaniel *et al.*, 1982; Nadabo *et al.*, 1980) may also have contributed to the establishment of the rust in this area.

Results from the logistic analyses are consistent with the hypothesis that climatic factors affect both the host and pathogen in this interaction. Teliospore germination of the rust is favored by cool, moist conditions (Liddell *et al.*, 1993) and the presence of rust on herbarium specimens was favored by wetter-than-average conditions in the fall of collection. Higher temperatures in the spring quarter also apparently favored the occurrence of rust on herbarium specimens, although the mechanisms responsible for this observation are not clear.

Heitschmidt (1979) found the growth of *Gutierrezia* spp. in Texas was favored by higher-than-average rainfall in May and lower-than-average daily maximum temperatures in April. Logistic regression analysis of the effect of average daily maximum temperature in April and precipitation in May during the year of collection on the number of herbarium specimens diseased with *P. grindeliae* showed no significant relationship to rust occurrence. Thus the monthly climatic factors that favor the growth of the host (Heitschmidt, 1979) do not correspond completely with the factors that favor the occurrence of *P. grindeliae*.

Although the logistic regression analysis implies no cause and effect between independent and dependent variables, the analysis can provide a valuable basis for the formulation of hypotheses. The occurrence of *P. grindeliae*, based on herbarium specimens, may depend on a moderate level of thermal stress to the host plant in spring, perhaps increasing susceptibility. Growth of *Gutierrezia* is favored by lower-than-average temperatures in spring (Heitschmidt, 1979); yet rust occurrence on herbarium specimens was correlated with higher mean spring temperatures. The positive correlation between fall precipitation and the occurrence of *P. grindeliae* appears to directly affect the pathogen, leading to higher levels of teliospore germination and host infection.

We realize there are significant problems in relying on data derived from herbarium specimens to conduct epidemiological and biogeographic studies as plants collected at a site are probably not random samples. Collectors generally select for the best, or representative, specimens and may have avoided diseased plants. These collections were made by hundreds of collectors over the past 100 years, and it is impossible to know exactly what factors influenced the collection of a particular specimen. Older specimens may be in poor condition, providing little helpful data. In addition, the number of positive specimens in any given collection is relatively low. Collection sites may not be chosen precisely and often are not well documented. Repeated collection at a site was rare. There are certainly changes in development and landscaping that lower the likelihood of success when attempting to revisit an established site. However, despite these limitations, herbarium specimens remain the only way to gather information of historical occurrence of many pathogens of noneconomically important plants.

Puccinia grindeliae has been established in native populations of *Gutierrezia* spp. in New Mexico and Arizona for many years and does not appear to have had a significant impact on those *Gutierrezia* populations over extended periods of time. Rather than reducing the range and density of *Gutierrezia* spp., *P. grindeliae* has spread along with *G. sarothrae* throughout rangelands in the Southwest over the past 100 years, as may be expected for a biotrophic pathogen at evolutionary stasis with its host. The coevolution of rust pathogens with their hosts has been well established for many systems and it appears that *Puccinia grindeliae* has been coevolving with *Gutierrezia* for a considerable time. Given that broom snakeweed is endemic to the southwestern U.S., this result indicates that the long-term effectiveness of *P. grindeliae* or other endemic species as biological control agents of *Gutierrezia* spp. in New Mexico and Arizona appears to be limited. Future work to increase the range of *P. grindeliae* artificially to areas where it is not now present may provide a low level of biological stress on broom snakeweed and enhance the effectiveness of other control and management methods.

REFERENCES

Brenckle, J.F. (1918). North Dakota Fungi—II. *Mycologia* **10**, 199–221.

Cummins, G.B. (1978). *Rust fungi on legumes and composites in North America*. University of Arizona Press: Tucson, AZ.

Cummins, G.B. (1979.) Annotated, illustrated, host index of Sonoran Desert rust fungi. *Mycotaxon* **10**, 1–20.

Farr, D.F., Bills, G.F., Chamuris, G.P and Rossman, A.Y. (1989). *Fungi on plants and plant products in the United States*. APS Press: Minneapolis MN.

Gilbertson, R.L. and McHenry, J. (1969). Check list and host index for Arizona rust fungi. *University of Arizona Agricultural Experiment Station Technical Bulletin*. **186**, 1–40.

Heitschmidt, R.K. (1979). Relative annual broomweed abundance as related to selected climatic factors. *Journal of Range Management*. **32**, 401–403.

Lane, M.A. (1982). Generic limits of *Xanthocephalum*, *Gutierrezia*, *Amphiachyris*, *Gymnosperma*, *Greenella*, *Thurovia* (Compositae: Astereae). *Systemic Botany* **7**, 405–416.

Lane, M.A. (1983). Taxonomy of *Xanthocephalum* (Compositae: Astereae). *Systemic Botany* **8**, 305–316.

Lane, M.A. (1985). Taxonomy of *Gutierrezia* (Compositae: Astereae) in North America. *Systemic Botany* **10**, 7–28.

Liddell, C.M., Waddell, C.A. and McEntee, J.P. (1993). Teliospore germination in *Puccinia grindeliae*, rust of the rangeland weed *Gutierrezia sarothrae*. *Plant Disease* **77**, 149–152.

McDaniel, K.C., Pieper, R.D. and Donart, G.B. (1982). Grass response following thinning of broom snakeweed. *Journal of Range Management* **35**, 142–145

McEntee, J.P. and Liddell, C.M. (1991). Geographic distribution of *Puccinia grindeliae* on *Gutierrezia sarothrae* in the southwestern USA from 1891 to 1991. *Phytopathology* **81**, 1149 (abstr.).

Nadabo, S., Pieper, R.D., and Beck, R.F. (1980). Growth patterns and biomass relations of *Xanthocephalum sarothrae* (Pursh) Shinners on sandy soils in southern New Mexico. *Journal of Range Management*. **33**, 394–397.

National Oceanic and Atmospheric Administration, Environmental Data and Information Service, National Climatic Center, Department of Commerce, Arizona and New Mexico Sections (1905–1991).

Peck, C.S. (1879). New species of fungi. *Botanical Gazette*. **4**, 126–128.

SAS Institute Inc. (1989). *SAS/STAT User's Guide*, Version 6, Fourth Edition, Volume 2. SAS Institute: Cary, NC.

Solheim, W.G. (1934). Mycoflora Saximontanensis Exsiccata Centum I. *University of Wyoming Publication Botany* **1**, 219–232.

Solheim, W.G. (1940). Mycoflora Saximontanensis Exsiccata Centum III. *University of Wyoming Publication* **7**, 29–42.

Solheim, W.G. (1943). Mycoflora Saximontanensis Exsiccata Centum IV. *University of Wyoming Publication* **10**, 33–46.

Solheim, W.G. (1954). Mycoflora Saximontanensis Exsiccata Centum VI. *University of Wyoming Publication* **18**, 71–82.

Solheim, W.G. and Cummins, G.B. (1957). Mycoflora Saximontanensis Exsiccata Centum VIII. *University of Wyoming Publication* **21**, 56–167.

Solheim, W.G. and Cummins, G.B. (1959). Mycoflora Saximontanensis Exsiccata Centum X. *University of Wyoming Publication* **23**, 38–51.

Solheim, W.G. and Cummins, G.B. (1970). Mycoflora Saximontanensis Exsiccata Centum XIII. *University of Wyoming Publication* **36**, 37–50.

Solheim, W.G. and Cummins, G.B. (1970). Mycoflora Saximontanensis Exsiccata Centum XV. *University of Wyoming Publication* **36**, 69–80.

Solheim, W.G. and Cummins, G.B. (1979). Mycoflora Saximontanensis Exsiccata Centum XVII. *Mycotaxon* **8**, 395–401.

Te Beest, D.O., Yang, X.B. and Cisar, C.R. (1992). The status of biological control of weeds with fungal pathogens. *Annual Review of Phytopathology* **30**, 637–657.

Williams, J.L., ed. (1986). *New Mexico in Maps*. 2nd Edn. University of New Mexico Press: Albuquerque, NM.

Williams, J.L. and McAllister, P.E., eds. (1981). *New Mexico in Maps*. University of New Mexico Press: Albuquerque NM.

Yohem, K.H., Cummins, G.B. and Gilbertson, R.L. (1985). Revised list and host index of Arizona rust fungi. *Mycotaxon* **22**, 451–468.