BRISTLECONE PINE DWARF MISTLETOE: *ARCEUTHOBIUM MICROCARPUM* SUBSP. *ARISTATAE* (VISCACEAE), A NEW SUBSPECIES OF WESTERN SPRUCE DWARF MISTLETOE FROM NORTHERN ARIZONA

Jared M. Scott

School of Forestry
Northern Arizona University
Flagstaff, Arizona 86011, U.S.A.
Jared.Scott@nau.edu

Robert L. Mathiasen

School of Forestry
Northern Arizona University
Flagstaff, Arizona 86011, U.S.A.
Robert.Mathiasen@nau.edu

ABSTRACT

We describe **Arceuthobium microcarpum** subsp. **aristatae** (Viscaceae), a parasite of bristlecone pine (*Pinus aristata* Engelm.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in northern Arizona. Morphological and phenological data were used to compare *A. microcarpum* populations parasitizing bristlecone pine on the San Francisco Peaks, Arizona, with populations on Engelmann spruce and blue spruce (*Picea pungens* Engelm.) from other locations in Arizona and New Mexico. Morphological, phenological, and host susceptibility differences support the classification of the populations of *A. microcarpum* on the San Francisco Peaks and Kendrick Peak in northern Arizona as a new subspecies.

RESUMEN

Se describe **Arceuthobium microcarpum** subsp. **aristatae** (Viscaceae), un parásito de *Pinus aristata* Engelm. y de *Picea engelmannii* Parry ex Engelm. en el norte de Arizona. Se usaron datos morfológicos y fenológicos para comparar poblaciones de *A. microcarpum* que parasitan a *Pinus aristata* de San Francisco Peaks, Arizona, con poblaciones que parasitan a *Picea engelmannii* y a *Picea pungens* Engelm. en otras localidades de Arizona y Nuevo México. Diferencias morfológicas, fenológicas y de susceptibilidad de los hospedadores fundamentan la clasificación de las poblaciones de *A. microcarpum* de San Francisco Peaks y de Kendrick Peak en el norte de Arizona como una subespecie nueva.

KEY WORDS: *Arceuthobium, Picea engelmannii, Picea pungens, Pinus aristata,* Arizona

Western spruce dwarf mistletoe (*Arceuthobium microcarpum* (Engelm.) Hawksw. & Wiens) is an important parasite of blue spruce (*Picea pungens* Engelm.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in the southwestern United States (Mathiasen et al. 1986; Hawksworth & Wiens 1996). It occurs as far south as the Pinaleño Mountains, Arizona and Sacramento Mountains, New Mexico and as far north as the Kaibab Plateau, Arizona. However, western spruce dwarf mistletoe is most common in the White Mountains, Arizona and Mogollon Mountains, New Mexico (Mathiasen et al. 1986; Hawksworth & Wiens 1996). On the San Francisco Peaks, Arizona, it also parasitizes Rocky Mountain bristlecone pine (*Pinus aristata* Engelm.) (Mathiasen & Hawksworth 1980). Initially, the dwarf mistletoe infecting bristlecone pine on the San Francisco Peaks was classified as limber pine dwarf mistletoe (*Arceuthobium cyanocarpum* (A. Nelson ex Rydb.) Coulter & Nelson) by Hawksworth and Wiens (1972). It was later classified as *A. microcarpum* based on its host affinities and chemical characters (flavonols) (Crawford & Hawksworth 1979; Mathiasen & Hawksworth 1980; Hawksworth & Wiens 1996). Although Mathiasen and Hawksworth (1980) reported morphological, phenological, and host susceptibility differences between the *A. microcarpum* populations on the San Francisco Peaks and other *A. microcarpum* populations in the Southwest, they did not recommend giving the San Francisco Peaks populations taxonomic status at that time. In 2006, we began a more detailed analysis of the morphological characteristics of the *A. microcarpum* populations in Arizona. Our data further substantiated the differences between the *A. microcarpum* populations on the San Francisco Peaks and those in other mountain ranges of Arizona first reported by Mathiasen and Hawksworth (1980). Because of the differences in plant size, plant color, phenology, host affinities, and geographic isolation of

the dwarf mistletoe populations on the San Francisco Peaks, and nearby Kendrick Peak, there is sufficient evidence to describe these populations as a new subspecies of *A. microcarpum*.

Arceuthobium microcarpum (Engelm.) Hawksw. & Wiens subsp. **aristatae** J.M. Scott & Mathiasen, subsp. nov. (**Figs. 1–2**). TYPE: U.S.A. ARIZONA. Coconino Co.: near summit of Schultz Peak, a southeast subsidiary ridge of the San Francisco Peaks, Coconino National Forest, elev. 3,060 m, Lat. 35° 18' 43" N, Long. 111° 37' 52" W, parasitic on *Pinus aristata*, 8 Aug 2006, *J.M. Scott 2006-6* (HOLOTYPE: ASC; ISOTYPES: JEPS, UNM, US).

Plantae (1–)3(–7) cm altae; surculi principales basi (1–)1.8(–3) mm diam; fructus maturi 3.3 × 2.1 mm; anthesis mense Julio–Augusto; fructus maturitas Augusto–Septembri; in *Pinus aristata* et *Picea engelmannii* parasiticae.

Male plants (0.8–)2.7(–7.0) cm in height, basal diameter of dominant plants (1.0–)1.8(–3.0) mm; female plants (1.4–)3.6(–7.0) cm in height, basal diameter of dominant plants (0.6–)1.8(–3.0) mm; male and female plant plants primarily light green, but some brown-green or purple; male flower diameter 2.5 mm, perianth lobe dimensions 1.2 × 1.0 mm, anther diameter 0.5 mm, distance from anther to perianth tip 0.5 mm; fruit dimensions 3.3 × 2.1 mm; seed dimensions 2.4 × 1.1 mm.

Common name.—bristlecone pine dwarf mistletoe.

Etymology.—We selected *aristatae*, a name that indicates the principal host of this dwarf mistletoe is *Pinus aristata*.

Phenology.—Anthesis from early July to late-August with peaks in late-July to early-August; seed dispersal from mid-August to late-September with peaks in mid- to late-August to early-September.

Habit.—Parasitic principally on *Pinus aristata* and occasionally on *Picea engelmannii* on Schultz Peak, parasitic principally on *Picea engelmannii* in the Inner Basin of the San Francisco Peaks and on nearby Kendrick Peak. Not known on *Picea pungens*. Rarely infects *Pinus flexilis* James and *Abies lasiocarpa* (Hook.) Nutt. on Schultz Peak.

Distribution.—Bristlecone pine dwarf mistletoe only occurs in three small populations on the San Francisco Peaks (Schultz Peak, Weatherford Trail, and Inner Basin, Fig. 3). It also occurs near the summit of Kendrick Peak (Fig. 4). It ranges in elevation from 2890 to 3130 m on Schultz Peak.

METHODS

Collection Locations.—In 2006 and 2007, plants of *A. microcarpum* were collected from 18 populations in Arizona (Appendix A; Appendices A–F available online at http://www.for.nau.edu/SOFArchive/MSF-Students/JMScott/20090325.pdf). Four populations were sampled near Flagstaff, Arizona (host plants): Schultz Peak (bristlecone pine and Engelmann spruce), Weatherford Trail (bristlecone pine), Inner Basin (bristlecone pine and Engelmann spruce) (Fig. 3), and Kendrick Peak (Engelmann spruce) (Fig. 4). A total of 12 populations of *A. microcarpum* were sampled in the White Mountains (host plants): Cache Cienega (blue and Engelmann spruce), Coleman Creek (blue spruce), Hannagan Creek (blue spruce), Johns Canyon (blue spruce), Lee Valley (blue spruce), Williams Valley (blue spruce), Forest Road 249 (blue spruce), Forest Road 402 (blue and Engelmann spruce), and Forest Road 72 (blue and Engelmann spruce) (Fig. 4). In addition, two populations were sampled from the North Rim of the Grand Canyon: Point Royal Road (blue spruce) and Route 67 (blue spruce).

In 1975 and 1976, plants of *A. microcarpum* were collected by the junior author from the same locations and hosts on the San Francisco Peaks that were sampled in 2006–07. Plants were also collected from the North Rim of the Grand Canyon (blue spruce), the White Mountains (blue and Engelmann spruce), the Mogollon Mountains (blue spruce), and the Pinaleño Mountains (Engelmann spruce) (Fig. 4).

Morphological Measurements.—The following morphological characters of male plants were measured: dominant plant height, dominant plant basal diameter, flower diameter, anther diameter, perianth lobe length, perianth lobe width, and distance from the outer edge of the anther to the tip of the perianth lobe. The following morphological characters were measured for female plants: dominant plant height, dominant plant basal diameter, length and width of both fruits and seeds. The color of plants, fruits, and seeds were recorded. Plant heights and basal diameters were measured with digital calipers to the nearest 0.1 cm. All

Fig. 1. Holotype of *Arceuthobium microcarpum* subsp. *aristatae* J.M. Scott & Mathiasen, subsp. nov., *J.M. Scott 2006-6*, 8 Aug 2006 (ASC). Photo by R.L. Mathiasen.

Fig. 2. (**Top**) Male *Arceuthobium microcarpum* subsp. *aristatae* infecting *Picea engelmannii* in the Inner Basin of the San Francisco Peaks, Arizona. Photo taken on 27 May 2008 by J.M. Scott. (**Bottom**) Male *Arceuthobium microcarpum* subsp. *aristatae* infecting *Pinus aristata* on Schultz Peak, Arizona. Photo taken 30 May 2008 by J.M. Scott.

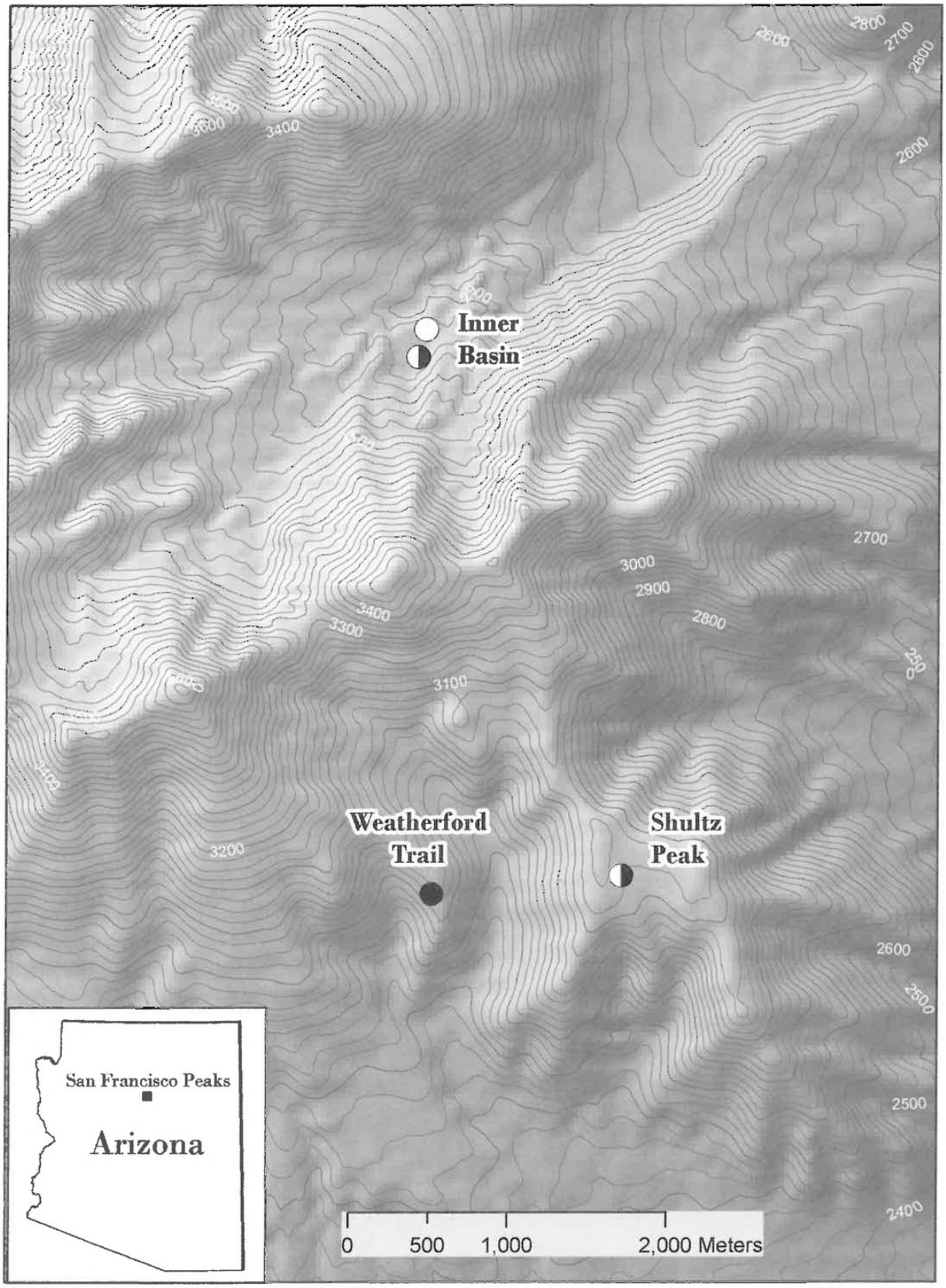

Fig. 3. The four infestations of western spruce dwarf mistletoe on the San Francisco Peaks, AZ. Dark circles indicate an infestation on bristlecone pine, white circles indicate an infestation on Engelmann spruce, half-dark and white circles indicate an infestation on both bristlecone pine and Engelmann spruce.

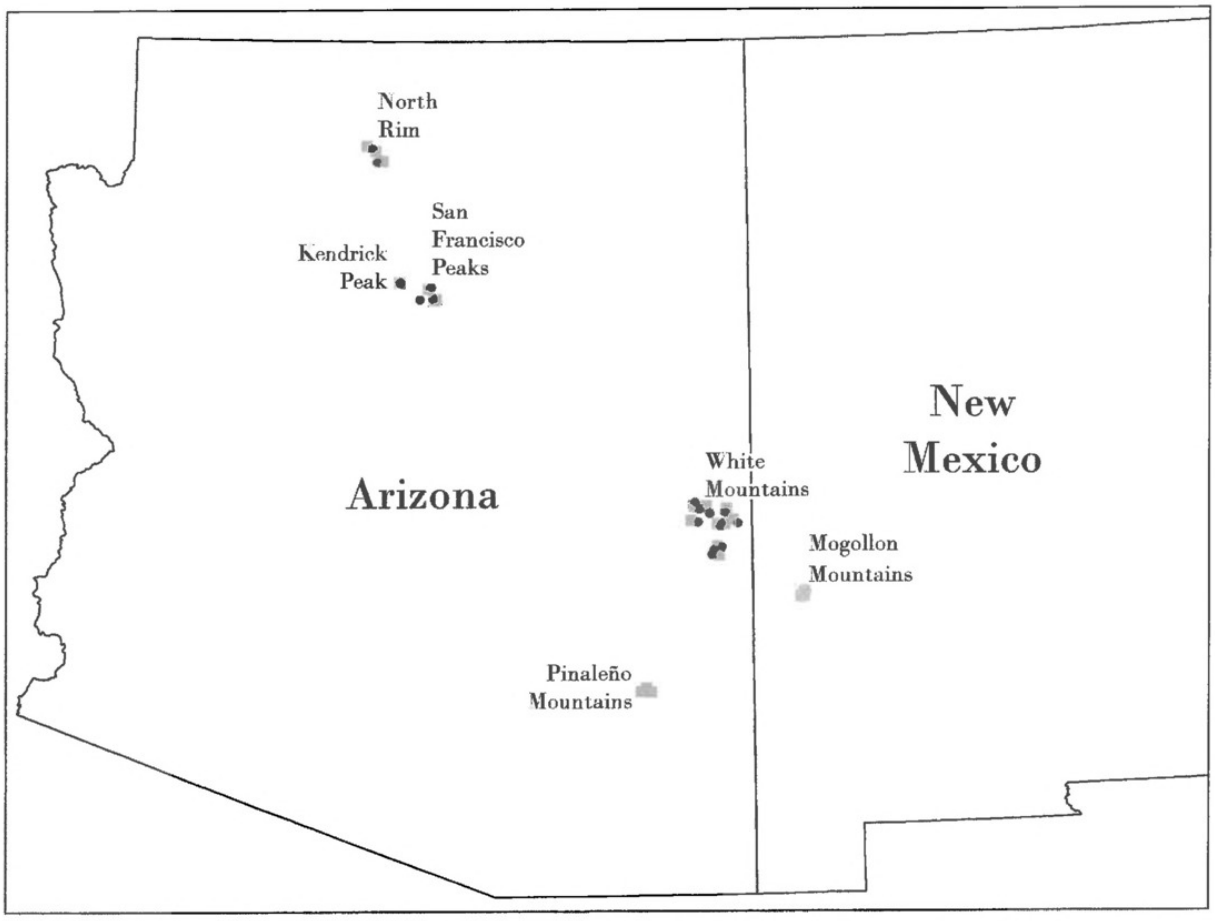

Fig. 4. Approximate locations for plant collections of western spruce dwarf mistletoe in 1975 and 1976 (gray squares) and in 2006 and 2007 (closed circles). Plants were collected from approximately the same locations for the White Mountains, San Francisco Peaks, Kendrick Peak, and the North Rim of the Grand Canyon.

other morphological characters were measured using a 10× hand lenses with a micrometer to the nearest 0.1 mm. Male plants were collected during peak anthesis and female plants were collected when fruits were mature. Over 20 male or female plants were collected for each population and morphological measurements were completed using ten randomly selected plants for each population sampled. Not all of the morphological characters that were measured in 2006–07 were measured for the 1970s data. Characters examined for both datasets included male and female plant height and basal diameter, flower diameter, perianth lobe length and width, fruit length and width, seed length and width, and plant color.

Phenology Observations.—Anthesis and seed dispersal data were recorded when plants were collected for morphological measurements in 1975, 2006, and 2007. Data for the last two years were primarily from the San Francisco Peaks and Kendrick Peak due to frequent visits to these areas. During these years, the White Mountains were only visited twice each year: once during anthesis and again during seed dispersal. Therefore, the precise times of peak anthesis and seed dispersal were estimated for the White Mountains in 2006–07. In 1975, phenology data was collected from the San Francisco Peaks, Kendrick Peak, White Mountains, and Pinaleño Mountains, Arizona.

Host Susceptibility.—In 2008, temporary 0.012 ha (radius 6 m) plots were established around 26 severely infected bristlecone pines on Schultz Peak and 13 severely infected Engelmann spruces in the Inner Basin. In each plot, all trees > 1.4 m in height were examined for dwarf mistletoe infection. For each tree, species, diameter at breast height (dbh; to the nearest cm), and a dwarf mistletoe rating (DMR, Hawksworth 1977) were

recorded. These data provided information on the relative susceptibility of bristlecone pine and Engelmann spruce to dwarf mistletoe infection on Schultz Peak and for Engelmann spruce in the Inner Basin.

Data Analysis.—Morphological data were combined from hosts on the San Francisco Peaks (bristlecone pine and Engelmann spruce) and Kendrick Peak (Engelmann spruce) and also for the White Mountains and North Rim (blue and Engelmann spruce) for analyses. Morphological data from 1975 and 1976 were included within these two data sets, but the 1970s data also included morphological measurements from the Mogollon and Pinaleño Mountains. A one-way analysis of variance (ANOVA, P-value ≤ 0.05) was used to test for significant differences between the means of each morphological character measured.

RESULTS

Morphological Data.—On average, male and female plants of western spruce dwarf mistletoe (WSDM, subsp. *microcarpum*) were larger than those of bristlecone pine dwarf mistletoe (BPDM, subsp. *aristatae*) and the differences in size were significantly different (Table 1, Appendices B–E, online). Although the largest plants we measured in 2006 and 2007 were collected from blue spruce in the White Mountains (Appendix B), the largest plants measured in the 1970s were from Engelmann spruce in the Pinaleño Mountains (Appendix E). Plant heights for the 1970s data were slightly larger than those for the 2006–07 data for BPDM, but both sets of data demonstrated that plants of WSDM were larger than BPDM. The mean basal diameter of male plants was similar, but the mean basal diameter of female WSDM plants was larger on average than female plants of BPDM and significantly different. The means for flower diameters, fruit lengths, and seed widths were significantly different, even though the differences were only about 0.1 mm or less (Table 1).

The color of male and female plants of BPDM was commonly light green or green-brown. However, many plants on the San Francisco Peaks appeared purple (Fig. 2). The color of male and female plants of WSDM was similar to BPDM, except that some plants in the White Mountains were green-blue.

Phenology.—Peak anthesis for BPDM occurred one to two weeks earlier on the San Francisco Peaks than for WSDM in the White Mountains in 2006 and 2007. Seed dispersal of BPDM also starts and ends one to two weeks earlier on the San Francisco Peaks than seed dispersal of WSDM in the White Mountains. The 1970s observations also found that BPDM flowers and disperses seed earlier than WSDM (Mathiasen & Hawksworth 1980).

Host Susceptibility.—Infection of bristlecone pine on Schultz Peak was 96% (n = 111) indicating it is a principal host of bristlecone pine dwarf mistletoe there. However, infection of Engelmann spruce was only 34% (n = 224) on Schultz Peak placing it in the occasional host class of Hawksworth and Wiens (1996). Engelmann spruce is clearly much less susceptible than bristlecone pine on Schultz Peak. However, infection of Engelmann spruce in the Inner Basin, just 5 km north of Schultz Peak, was 94% (n = 101). All of the bristlecone pines growing near severely infected Engelmann spruces in the Inner Basin were infected, but there are only about 10 bristlecone pines in the area. We also observed rare infection of limber pine (2 trees) and subalpine fir (3 trees) by BPDM on Schultz Peak.

Table 2 summarizes the principal morphological and physiological differences between BPDM and WSDM used to distinguish the two subspecies. The shoot heights, colors, and phenology, of BPDM on the San Francisco Peaks and Kendrick Peak were similar enough to group them as one population. Morphological data from Mathiasen and Hawksworth (1980) and our data demonstrated that BPDM plant heights were smaller than for WSDM populations in southern Arizona and central New Mexico. The differences in mean plant height between BPDM and WSDM were statistically significant. Additionally, color differences were found between BPDM (purple plants) and WSDM (blue-green plants). Furthermore, the periods of flowering and seed dispersal for BPDM on the San Francisco Peaks occurred one to two weeks earlier than for populations of WSDM in the White Mountains in 1975–76 and 2006–07.

Another important set of physiological/genetic characteristics that separates BPDM from WSDM are their host affinities. Bristlecone pine was the principal host of BPDM on Schultz Peak (96% infection), but we found that only 34% of the Engelmann spruce were infected there. Mathiasen and Hawksworth (1980) also

TABLE 1. Comparison of morphological characters of *Arceuthobium microcarpum* subsp. *aristatae* and *A. microcarpum* subsp. *microcarpum*. Data combine measurements from 1975–76 and 2006–07 for all hosts and are presented as means (ranges) [n]. Characters with an asterisk had significantly different means using ANOVA ($P \leq 0.05$). The means for seed width were rounded to the nearest 0.1 mm, but actual values were significantly different.

Character	*A. microcarpum* subsp. *aristatae*	*A. microcarpum* subsp. *microcarpum*
Plant Height (cm)		
Male*	2.7(0.8–7.0) [152]	5.6(1.8–14.9) [283]
Female*	3.6(1.4–7.0) [177]	6.4(2.0–15.7) [353]
Basal Diameter (mm)		
Male	1.8(1.0–3.0) [121]	1.9(0.8–3.4) [157]
Female*	1.8(0.6–3.0) [167]	2.0(0.8–3.8) [313]
Flower Diameter (mm)*	2.5(1.8–4.0) [287]	2.4(1.6–3.1) [266]
Fruit Length (mm)*	3.3(3.5–5.1) [281]	3.4(3.4–5.2) [440]
Fruit Width (mm)	2.1(1.7–2.9) [281]	2.2(1.9–3.1) [440]
Seed Length (mm)	2.4(1.5–3.4) [107]	2.4(1.3–3.4) [224]
Seed Width (mm)*	1.1(0.8–1.4) [107]	1.1(0.7–1.5) [244]

TABLE 2. Summary of the principal morphological and physiological differences between *Arceuthobium microcarpum* subsp. *aristatae* and *A. microcarpum* subsp. *microcarpum*.

Character	*A. microcarpum* subsp. *aristatae*	*A. microcarpum* subsp. *microcarpum*
Mean Plant Height (cm)		
Male Plants	2.7	5.6
Female Plants	3.6	6.4
Plant Color	Light green; green-brown; purple	Light green; green-brown; blue-green
Peak Flowering Period	One to two weeks earlier than subsp. *microcarpum*	One to two weeks later than subsp. *aristatae*
Host Susceptibility[1]		
Bristlecone pine	Principal	Unknown
Engelmann spruce	Principal/Occasional[2]	Principal
Blue spruce	Unknown	Principal
Limber pine	Rare	Unknown
Subalpine fir	Rare	Rare
Southwestern white pine	Unknown	Immune

[1]Host susceptibility classification categories are described in Hawksworth and Wiens (1996). The host susceptibility designations used for *A. microcarpum* subsp. *micorcarpum* are based on information in Hawksworth and Wiens (1996) also.

[2]Engelmann spruce was classified as a principal host for subsp. *aristatae* in the Inner Basin of the San Francisco Peaks and on Kendrick Peak, Arizona, but it was an occasional host of this mistletoe on Schultz Peak.

reported that bristlecone pine was the principal host of BPDM on Schultz Peak, and they reported a similar level of infection for Engelmann spruce (32%), but they used a different method of collecting infection data; a systematic sampling design using 27 rectangular plots. Although they classified Engelmann spruce as a secondary host of BPDM on Schultz Peak, the low incidence of infection we found indicates Engelmann spruce should be classified as an occasional host there. Based on our observations and those of Lynch (2004), blue spruce is more susceptible to infection by WSDM than Engelmann spruce, but both are principal hosts of WSDM. Because blue spruce has not been reported on Kendrick Peak or the San Francisco Peaks, we were unable to collect infection data for BPDM on this host. There is also a report of dwarf mistletoe on Chihuahua spruce (*Picea chihuahuana* Martínez) in northern Mexico by Ledig et al. (2000) which we assumed would be WSDM. However, our examination of several Chihuahua spruce populations in Chihuahua and Durango

reported to be infested with dwarf mistletoe, indicated that the spruces were infected with spruce broom rust (*Chrysomyxa arctostaphyli* Dietel) and not dwarf mistletoe. Spruce broom rust induces the formation of witches' brooms on Chihuahua spruce that are similar to those caused by dwarf mistletoes (Cibrián et al. 2007), which was undoubtedly the reason for the report of dwarf mistletoe on Chihuahua spruce in Mexico. Therefore, none of the Mexican species of *Picea* have been reported as the host of a dwarf mistletoe thus far (Hawksworth et al. 2002).

Hawksworth and Wiens (1972, 1996) defined a subspecies as geographically restricted populations having small, but consistent variations. Variations in dwarf mistletoe plant size, color, host range, and phenology have been used as the primary characteristics to identify subspecies of dwarf mistletoe (Hawksworth & Wiens 1965; Hawksworth & Wiens 1972, 1977, 1996; Hawksworth et al. 1992; Wass & Mathiasen 2003; Mathiasen 2007; Mathiasen & Daugherty 2007). Furthermore, the geographic isolation of the San Francisco Peak/Kendrick Peak BPDM populations is also consistent with Hawksworth and Wiens (1972, 1996) definition that a subspecies should be a "geographically restricted population."

ACKNOWLEDGMENTS

We thank M. Socorro González Elizondo for the Spanish translation for the Resumen. We also appreciate the field assistance of James White and Laine Smith in northern Arizona and Brian Howell in northern Mexico. Gregory M. Filip and Del Wiens provided helpful suggestions to an earlier version of the manuscript.

REFERENCES

Cibrian, T.D., D. Alvarado, and S.E. Garcia. (eds.). 2007. Forest diseases in Mexico. Universidad Autonoma Chapingo, Mexico.

Crawford, D.J. and F.G. Hawksworth. 1979. Flavonoid chemistry of *Arceuthobium* (Viscaceae). Brittonia 31:212–216.

Hawksworth, F.G. 1977. The 6-class dwarf mistletoe rating system. Gen. Techn. Rep. R.M. U.S. Forest Serv. 48:1–7.

Hawksworth, F.G. and D. Wiens. 1965. *Arceuthobium* in Mexico. Brittonia 17:213–238.

Hawksworth, F.G. and D. Wiens. 1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). Agriculture Handbook 401, USDA Forest Service, Washington, D.C.

Hawksworth, F.G. and D. Wiens. 1977. *Arceuthobium* in Mexico: Additions and range extensions. Brittonia 29: 411–418.

Hawksworth, F.G. and D. Wiens. 1996. Dwarf mistletoes: biology, pathology, and systematics. Agriculture Handbook 709, USDA Forest Service, Washington, D.C.

Hawksworth, F.G., D. Wiens, and B.W. Geils. 2002. *Arceuthobium* in North America. In: Mistletoes of North American conifers. B.W. Giels and T.D. Cibrian, tech. coords. Gen. Techn. Rep. R.M.R.S. U.S. Forest Serv. 98:29–56.

Hawksworth, F.G., D. Wiens, and D.L. Nickrent. 1992. New western North American taxa of *Arceuthobium* (Viscaceae). Novon 2:204–211.

Ledig, F.T., M. Mapula-Larreta, B. Bermejo-Valazquez, V. Hernandez Reyes, C. Flores Lopez, and M.A. Capo Arteaga. 2000. Locations of endangered spruce populations in Mexico and the demography of *Picea chihuahuana*. Madroño 47:71–88.

Lynch, A.M. 2004. Fate and characteristics of *Picea* damaged by *Elatobium abietinum* (Walker) (Homoptera: Aphididae) in the White Mountains of Arizona. W. N. Amer. Naturalist 64:7–17.

Mathiasen, R.L. 2007. A new combination for Hawksworth's dwarf mistletoe (Viscaceae). Novon 17:217–221.

Mathiasen, R.L. and C.M. Daugherty. 2007. *Arceuthobium tsugense* subsp. *amabilae*, a new subspecies of hemlock dwarf mistletoe (Viscaceae) from Oregon. Novon 17:222–227.

Mathiasen, R.L. and F.G. Hawksworth. 1980. Taxonomy and effects of dwarf mistletoe on bristlecone pine on the San Francisco Peaks, Arizona. Res. Pap. R.M. 224:1–10.

Mathiasen, R.L., F.G. Hawksworth, and C.B. Edminster. 1986. Effects of dwarf mistletoe on spruce in the White Mountains, Arizona. Great Basin Naturalist 46:685–689.

Wass, E.F. and R.L. Mathiasen. 2003. A new subspecies of *Arceuthobium tsugense* (Viscaceae) from British Columbia and Washington. Novon 13:268–276.