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Numerical-Chemosystematic Studies of Infraspecific Variation in *Juniperus pinchotii*

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Key Word Index—*Juniperus pinchotii*; *Juniperus erythrocarpa*; Cupressaceae; Gymnospermae; terpenes; population differentiation; Pleistocene; numerical taxonomy.

Abstract—Twenty-seven populations of *Juniperus pinchotii* were sampled throughout the range of this taxon including several populations often referred to *J. erythrocarpa*. The terpenoids were extracted and analyzed by gas–liquid chromatography. Population differentiation was analyzed by analysis of variance and numerical taxonomy. *Juniperus pinchotii* appears to be fairly uniform in west Texas with considerable variation in the trans-Pecos region of Texas and the populations at Saltillo and Chihuahua City, Mexico. One population in Mexico just south of the Chisos Mountains was more similar to typical *J. pinchotii* from west Texas than to adjacent populations, inferring a past (Pleistocene?) connection with the west Texas populations. Pleistocene migrations are discussed. No evidence of hybridization nor introgression from other taxa was found. *Juniperus erythrocarpa* is informally treated as a part of *J. pinchotii* until additional studies have been completed.

Introduction

The red-berry juniper, *Juniperus pinchotii* Sudw., is a xerophytic shrub-tree which has usually been defined as having reddish-brown to yellow-red fruit (female cones) without bloom (glaucousness). It is generally conceded to range from the Texas panhandle southward to the trans-Pecos region (see Fig. 1). It is in the trans-Pecos Texas region that controversy has developed. Most of the plants in the Bouteloua grasslands (5000 ft) south of Alpine, Texas, have rose-colored fruit with bloom. These plants are sometimes lumped with *J. monosperma* Sarg. Cory [1] recognized this variation as *J. erythrocarpa* Cory, and Martinez [2] followed suit by recognizing *J. erythrocarpa* var. *coahuilensis* Martinez in Mexico. Van Melle [3] has further confused the issue by naming a "bright-red" fruited form of *J. pinchotii* as *J. texensis* van Melle from the Chisos Mountains of Big Bend, Texas. Correll [4] did not recognize either *J. erythrocarpa* or *J. texensis* as being distinct, although he did indicate that *J. monosperma* was present in the Alpine, Texas area. Adams [5] considered *J. erythrocarpa* and *J. texensis* as part of *J. pinchotii*, although it was admitted that *J. erythrocarpa* bears a strong morphological similarity to *J. monosperma*. However, on the basis of 80 terpenoid characters, *J. erythrocarpa* is clearly very similar to *J. pinchotii* [5].

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Figure 2 shows the population differentiation pattern discovered by Adams [5] using terpenoid data. Notice the marked divergence of the populations in extreme southwest Texas. These two populations had many trees with rose-coloured fruit. The study by Adams [5] utilized only 5 trees per population and these trees were often selected to detect possible hybrids. Therefore the sampling was quite biased (particularly in the Chisos Mountains). In addition, samples of the rose-colored variant were not taken from locations in Mexico. The purposes of this study were to resample the populations previously examined, taking 15 trees per population, to investigate additional populations of the rose-fruited variant (*J. erythrocarpa*) and to investigate the populational variability of *J. pinchotii* throughout its range. It was also felt that examination of the populational affinities would shed some light on the recent migration and evolution of *J. pinchotii*. The literature has been reviewed by Adams [5].

Results

The contoured similarity map (Fig. 3) reveals that *J. pinchotii* is fairly uniform throughout most of the Texas distribution. One major difference from Fig. 2 is that population 13 (Chisos Mountains) is much more similar to the rest of the central Texas populations than indicated in the previous study and correspond-

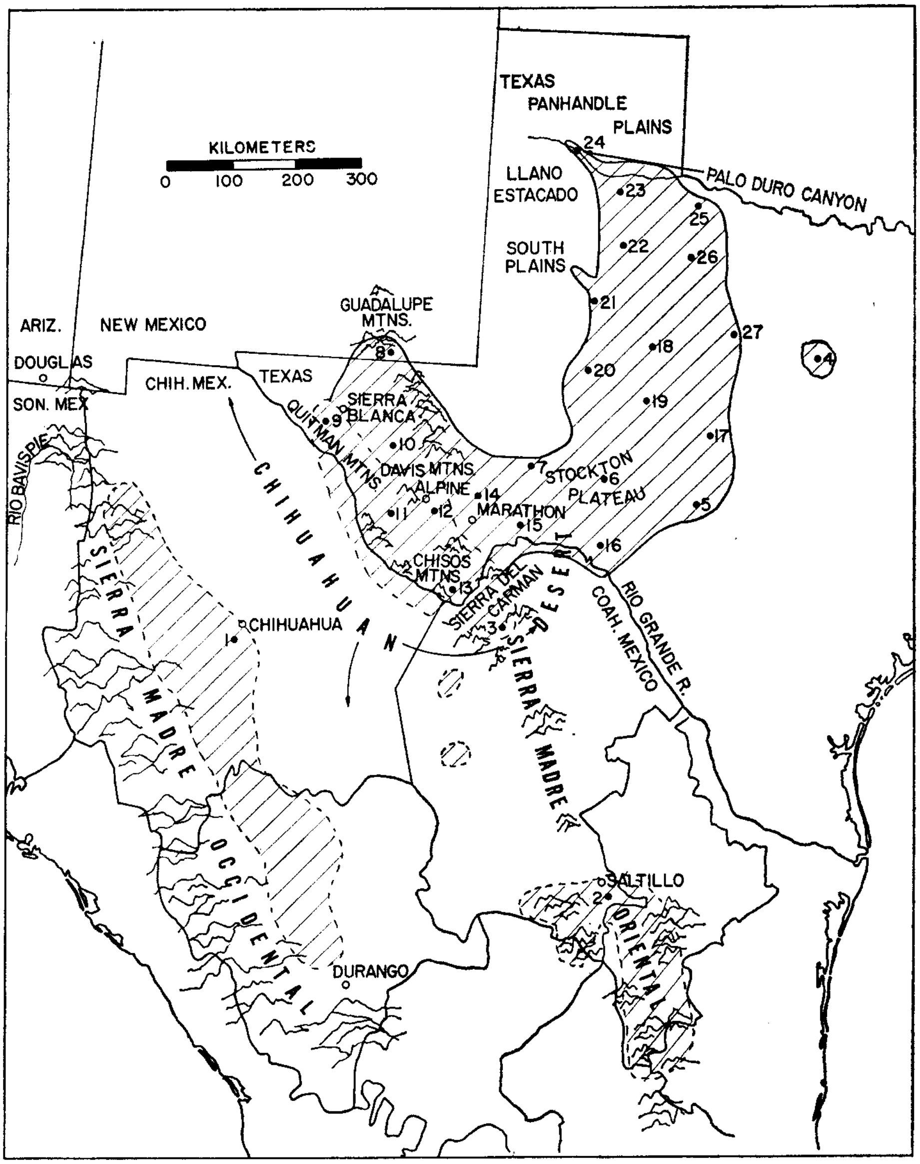

FIG. 1. DISTRIBUTION OF *JUNIPERUS PINCHOTII* AND POPULATIONS SAMPLED FOR THE PRESENT STUDY. Those areas enclosed in solid lines have been generally recognized as *J. pinchotii*. The areas enclosed in dashed lines are the rose-fruited variant (*J. erythrocarpa*). The northern extension of the rose-fruited taxon into northeastern Sonora and southern Arizona is not shown.

ingly less similar to population 12. This is principally due to the larger, more random samples taken in the present study. The most surprising result is the extremely high similarity of the Mexican populations to the typical *J. pinchotii* populations of west Texas. Rose-fruited variants were found in populations 1, 2, 9, 11 and 12. These populations did not cluster together (except for 11 and 12), but acted more as clinal variation. This is quite noticeable in Fig. 4, where 11 and 12 cluster together and then 1, 2 and 9 tail into the cluster. Notice the differentiation into the rose-fruited variant extends into the Chisos Mountains and into population 14. The high affinity of populations 13 and 19 is difficult to explain. Another unusual result is the appearance of the quite divergent Sierra Blanca population (9) which is only a few miles from typical *J. pinchotii.*

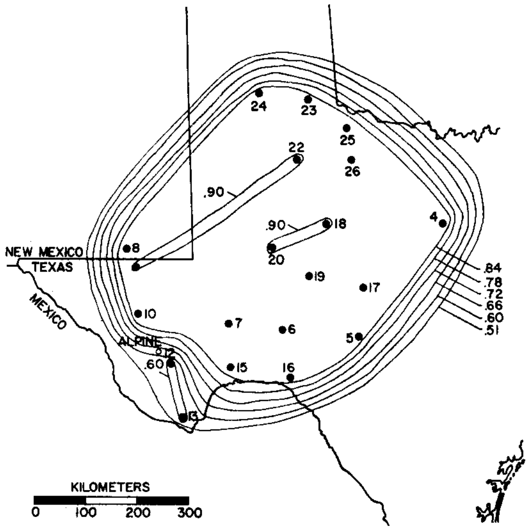

FIG. 2. CONTOURED SIMILARITY BASED ON 55 TERPENOIDS, *F* WEIGHTED FROM ADAMS [5]. The largest divergence was found in the southern trans-Pecos Texas area. These results were based on samples of 5 trees per population.

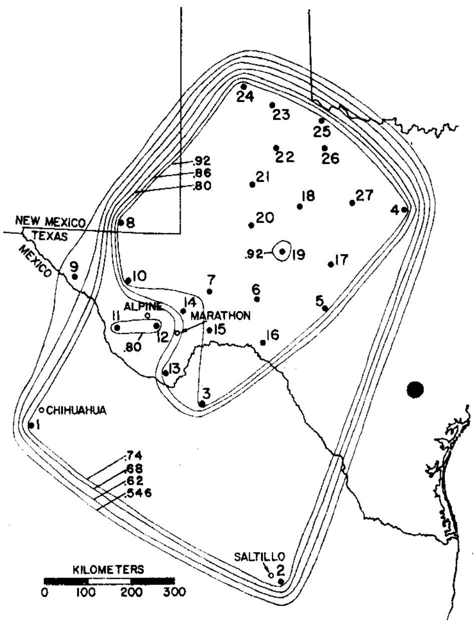

FIG. 3. CONTOURED SIMILARITY BASED ON 69 TERPENOIDS, *F*−1 WEIGHTED USING 15 TREES PER POPULATION. Notice the uniformity in central-west Texas and the divergence of populations 14, 13, 12, 11, 1, 2 and 9. Population 3 clusters strongly with the typical Texas populations.

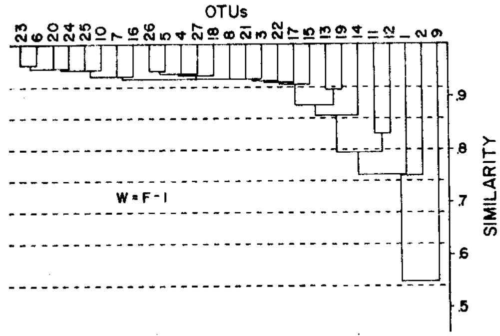

FIG. 4. A PHENOGRAM BASED ON THE 69 TERPENOIDS, *F*−1 WEIGHTED AND CLUSTERED BY SINGLE LINKAGE. The dashed lines show the contour levels used in Fig. 3. The quite disjunct populations 1 and 2 in Mexico are more similar to populations 11 and 12 than the adjacent population 9 in west Texas.

Discussion

The recent paleoclimate of the southwest has been quite variable [6]. The invasion and altitudinal descent of more mesic species has occurred as recently as the Wisconsin glacial (10 000 to 15 000 yr ago) [6–9]. Much of the area now occupied by *J. pinchotii* in central-west Texas was covered with pine-parkland during the Wisconsin stage [7].

The data from the current study indicates that *J. pinchotii* in west Texas probably existed as a widespread species in northern Mexico during the Pleistocene glaciations. Certainly the uppper portions of the Chihuahuan desert were crossed many times, leaving relicts on the various mesas and mountains now isolated in the desert. Two of these relict populations are probably in the Sierra del Carmen and the Chisos Mountains. When typical *J. pinchotii* is in contact with the rose-fruited variant, there appears to be an intergradation of both morphological and chemical characters. Whereas typical *J. pinchotii* thrives in the highly eroded, rocky areas, the variant is better adapted to the 5000-ft Bouteloua grasslands south of Alpine, Texas, and correspondingly in similar sites west of Chihuahua City, thence southward in the Bouteloua grasslands on the eastern foothills of the Sierra Madre Occidental. If the life zones descended 400–800 m [6] in the trans-Pecos region during the full Wisconsin (10–15 thousand yr b.p.), the Bouteloua grasslands at Alpine may have extended north and east into the Stockton plateau. The deviant *J. pinchotii* population north of Marathon (14) probably reflects past contact with the rose-fruited variants.

The population at Sierra Blanca (9) is

chemically, somewhat different from *J. pinchotii*, yet clearly more similar to it than to any taxon in the vicinity. Morphologically, this population differed little from the Alpine populations (11 and 12). Population 9 (Sierra Blanca) is rather small (perhaps a few hundred trees) on the north-facing slope of the Quitman Mountains. No other juniper population was seen in the area. Due to the small size and isolation of this population, perhaps either the founder's principle and/or genetic drift have fixed the peculiar pattern of terpenes in this population.

The rose-fruited variant has been called *J. pinchotii* in southern Arizona [10]. Recent field work indicates that indeed the taxon in western Chihuahua (popn 1), also occurs in the Rio Bavispe area south of Douglas, Arizona, northward into Arizona.

The one-seeded juniper group in Mexico is very complex. The movement of populations back and forth during the Pleistocene and even in the Tertiary [12] probably resulted in rapid evolution of specialized adaptations as empty niches appeared. When the glacial advances caused retreats into refugia and compression of life zones, somewhat dissimilar genomes were often reunited. This pool of variability is reflected in the mixture of closely related taxa around Saltillo, Coahuila [11].

The presence of a typical *J. pinchotii* population (3) in the Sierra del Carmen is clear evidence that *J. pinchotii* from central Texas was at one time continuously distributed into Mexico. For if birds carried seeds from central Texas, it seems very improbable that such a perfect correspondence could be obtained.

Finally it should be mentioned that the Mexican refugia hypothesis is supported by work on *J. ashei* Buch. [13]. A population of *J. ashei* which was similar to several populations in central Texas was also found south of the Sierra del Carmen.

Although the problems surrounding the evolution and phylogeny of *J. pinchotii* have not been fully resolved in this study, continued research of this type should elucidate these complex problems.

Experimental

Fifteen trees were sampled from each of the populations (Fig. 1) as outlined by Adams and Turner [14]. Voucher specimens are filed at Colorado State University. All samples were placed in a random sequence for distillation and analyses by assigning random numbers (3 digits) from a random number table and then ranking the numbers from low to high as suggested by Adams [15]. These procedures convert the temporal changes in foliage, oils, columns, etc., to random variables. Therefore population differentiation patterns can be easily separated from experimental errors in the statistical analyses phase. The volatile terpenoids were steam distilled for 2 hr as outlined by Adams [16] and the extracts were kept at −20° until analyzed by GLC under the same conditions as used by Adams [13]. The identities of the terpenoids of *J. pinchotii* are given in Adams [5]. The individual peaks were quantified with an Infotronics digital integrator with automatic punched output on an IBM 026 keypunch.

One hundred and ninety-six compounds were subjected to analysis of variance (ANOVA) to determine which characters showed significant differences among the populations. Fifty-seven compounds had highly significant F ratios (F=variance among populations/variance within populations). Sixty-nine compounds had F ratios greater than 1·0 and thus were used to compute $F-1$ weighted mean character difference (MCD) similarity measures as formulated in Adams [17] which is very similar to the F weighting used in the original study [5]. Clustering was by single linkage (nearest neighbor) as previously used.

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