United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**Research Paper
RM-292**

Genetic Variation in Great Plains *Juniperus*

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USDA Forest Service
Research Paper RM-292

June 1990

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Abstract

Height growth was tallest and survival highest, at age 5, in *Juniperus* trees from seed sources of *J. virginiana* originating in the central Great Plains (east-central Nebraska, western Iowa, and east north-central Kansas); and in trees from seed sources of *J. scopulorum* from northwest Nebraska and the High Plains (central to northeast Montana). Genotype x environment interaction in height was significant, but minimal in northern Great Plains plantations; it increased in the central plains plantations and primarily involved some southern sources. Age/age correlations indicated that selection of taller growing seed sources and taller trees within seed sources can be made at ages 2 and 5, respectively. Performance of *Juniperus* indicated an intermediate to broad adaptive mode.

Acknowledgments

The authors acknowledge the Forestry Committee of the Great Plains Agricultural Council for sponsoring this research, and thank the following cooperators: J. L. Van Deusen, USDA, For. Serv., Bottineau, ND; R. A. Cunningham, USDA, Agric. Res. Serv., Mandan, ND; N. E. Baer & P. R. Schaefer, S. Dak. St. Univ., Brookings; J. Barber, S. Dak. Dep. Game, Fish & Parks, Watertown; H. E. Hunter, J. G. Scheetz & L. K. Holzworth, USDA, Soil Conserv. Serv., Bozeman, MT; G. H. Fechner, Colo. St. Univ., Ft. Collins; W. R. Lovett and B. R. Chandler, Nebr. For. Serv., Lincoln; G. W. Peterson, USDA, For. Serv., Lincoln, NE; K. D. Lynch, Kans. St. Univ., Manhattan; C. G. Tauer, Okla. St. Univ., Stillwater; H. E. Stelzer & D. A. Houkal, For. Div., Mo. Dep. Conserv., Jefferson City; R. Fewin & J. Bryson, Tex. For. Serv., Lubbock; and J. T. Fisher & R. W. Newman, N. Mex. St. Univ., Las Cruces.

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Genetic Variation in Great Plains *Juniperus*

David F. Van Haverbeke and Rudy M. King

Management Implications

Eastern redcedar (*Juniperus virginiana* L.) and Rocky Mountain juniper (*J. scopulorum* Sarg.) are indigenous to much of the Great Plains; and because they are hardy, relatively disease resistant, and insect tolerant they are the most widely planted conifer species in protective and environmental plantings throughout the region. However, lack of genetic information about these Great Plains junipers has precluded identifying adapted seed sources for planting in specific areas, and has impeded their genetic improvement. Gaining this knowledge would greatly enhance the survival and successful establishment of these two important conifers in windbreak and environmental plantings throughout the Great Plains.

Introduction

The Great Plains of North America is a vast region, encompassing nearly one-fourth of the land mass of the United States. It extends uninterrupted through the central part of the continent from the prairie provinces of Canada to Mexico.

The taxonomy of *Juniperus* has been extensively investigated. Fassett (1944), Hall (1952a, 1952b), Van Haverbeke (1968), Schurtz (1971), von Rudloff (1975), Flake et al. (1978), Comer et al. (1982), and Adams (1983) characterized the junipers in the Great Plains as a variable population attributable to introgressive hybridization, with a clinal transition throughout the region. Van Haverbeke (1968) identified a zone of intermediacy extending northeasterly through northeast Colorado, northwest Nebraska, and southwest South Dakota. Trees to the north and west of this zone clinally manifested traits of *J. scopulorum* (Rocky Mountain juniper); trees to the south and east clinally embodied traits of *J. virginiana* (eastern redcedar).

Less is known about the adaptability patterns of *Juniperus* in the Great Plains, and little has been done to effect genetic improvement (Comer 1981, Fechner 1976, Janssen 1971, Van Deusen 1979). The objective of this research is to identify seed sources of *Juniperus* with rapid height growth, good survival, and wide adaptability for planting within the Great Plains.

Materials and Methods

Cones from 275 *Juniperus* trees exhibiting desirable windbreak characteristics were collected from natural stands throughout the Great Plains during 1973–1976 from seed zones designated by Cunningham (1975).

Cones were packaged in single-tree lots, placed in −16 °C storage, and depulped in mid-January 1977 as described by Van Haverbeke and Barnhart (1978). In

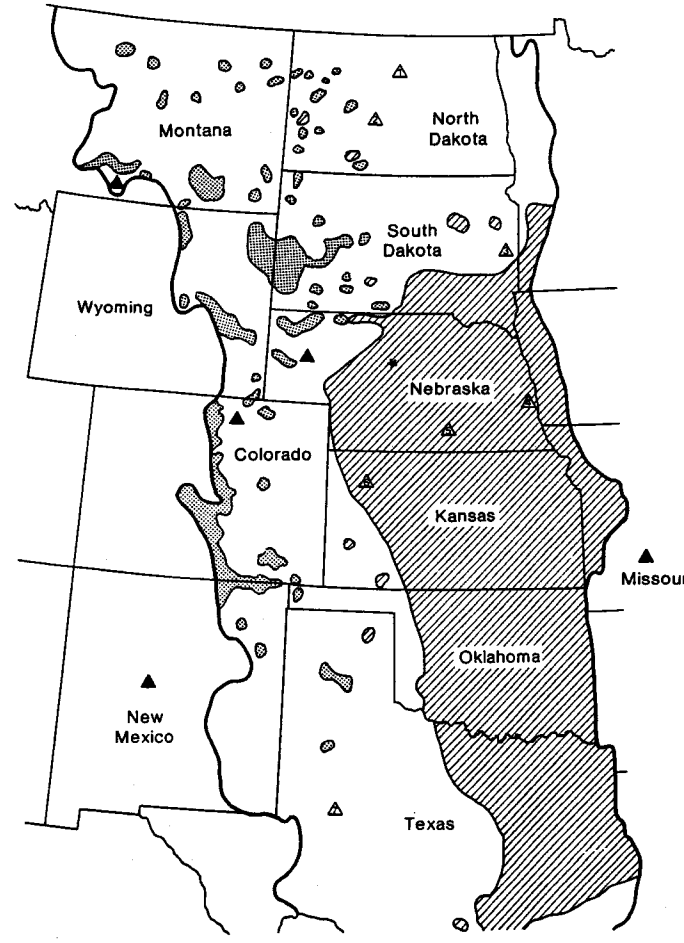

Figure 1.—The Great Plains region of the United States (dark line); distributions of *Juniperus* [*J. virginiana* L. (diagonal lines) and *J. scopulorum* Sarg. (shaded)] (Little 1971); and locations of nursery (*), and plantations (Δ). Numbers identify those plantations included in these analyses. 1—Towner, ND; 2—Mandan, ND; 3—Brookings, SD; 4—Plattsmouth, NE; 5—Hastings, NE; 6—Colby, KS; 7—Big Spring, TX.

mid-August 1977, the seed lots were sown in nursery beds at the USDA Forest Service Bessey Nursery near Halsey, in west-central Nebraska (fig. 1). Standard nursery procedures were followed. In March 1980 the 2-year-old seedlings were lifted and air-freighted to 12 cooperators throughout the Great Plains for field establishment (fig. 1).

The experimental design was a randomized, complete block with five replications. Fifth-year data were collected in the fall of 1984; evaluation criteria were height (cm) and survival (%).

Destruction of two plantations and missing data, variable numbers of seed sources, and poor survival because of drought in some plantations limited the principal analyses to seven plantations (fig. 1): Towner, ND; Mandan, ND; Brookings, SD; Plattsmouth, NE; Hastings, NE; Colby, KS; and Big Spring, TX. These seven plantations

represent the range of environmental conditions found throughout the Great Plains region.

In view of the clinal transition in *Juniperus* throughout the Great Plains, the junipers were analyzed as a single, variable population. Analyses of variance were applied to each plantation to evaluate variability in tree height and survival. For all plantations, significant variability among seed sources was evident, with a wider range in height response than survival. To interpret this variability and to provide an assessment across all plantations, ISODATA cluster analysis, combining height and survival, was used to group seed sources that had similar responses across the plantations (Ball and Hall 1965). Data were normalized to equalize the wide disparity between the scales and ranges of the two variables. Height was more variable, with a larger scale than survival; the latter was skewed toward 100% for many plantations.

Unlike a multiple range test, which identifies pairwise differences in height and survival among seed sources, the cluster analysis method segregates seed sources into groups (clusters) that perform consistently and similarly in all plantations. It identifies group centers in a way that maximizes between-group variation (or equivalently, minimizes within-group variation), and provides a general assessment of provenances across Great Plains environmental conditions. The result is a nonsubjective partitioning of the seed sources according to their height and survival, which can be evaluated for geographic pattern.

The combined height-survival clusters were evaluated using discriminant analysis (del Moral 1975). Revisions of cluster assignments were made using jackknifed classification functions computed by eliminating each source in turn from computation of within-group statistics (Jennrich and Sampson 1981, Lachenbruch and Mickey 1968).

To provide site-specific interpretations of the variability in height among seed sources, provenance transfer models were estimated for each plantation (Campbell 1974). Differences in latitude, longitude, and elevation between source locations and plantation locations were used as driving variables in the models that were estimated by least squares regression.

After each source was assigned to a cluster of similarly behaving sources, genotype x environment (G x E) interaction was assessed by computing a 2-factor analysis of variance with clusters and plantations as the factors. Significant interaction between clusters and plantations would indicate inconsistent response of clusters among plantations, or G x E interaction. G x E interaction was shown graphically for each cluster among the seven plantations.

Age/age correlations were computed to determine how early reliable seed source and individual tree selection could be made.

Calculations were made to determine the probability of selecting the better performing seed sources from zones included in the best performing cluster group.

Results

Height-Survival Clustering

The cluster discriminant analysis identified five clusters designated as the Central Plains, North Central Plains, South Central Plains, Northwest Plains, and Southern Plains clusters (table 1, fig. 2). The discriminant analysis indicated the clusters were predictable. A jackknifed estimate of correct classification for all clusters was 92%. Five of 85 sources were identified as incorrectly classified and were reassigned to new clusters (asterisked in table 1).

Sources with the tallest trees (158 cm) and high survival (86%) occurred in the Central Plains cluster (central and southeast Nebraska, western Iowa, south-central South Dakota, east-central Kansas) (fig. 2, table 2). The next best cluster, the North Central Plains cluster (142 cm, 86%), underlaid the Central Plains cluster in Nebraska and Kansas; it consisted of a stratum of slightly shorter and equally surviving seed sources, particularly

Table 1.—*Juniperus* seed source clusters as determined by height-survival cluster analysis.

Clusters																			
Central Plains (N=36) *J. virginiana*				North Central Plains (N=15) *J. virginiana*				South Central Plains (N=10) *J. virginiana*				Northwest Plains (N=17) *J. virginiana*				*J. scopulorum*				Southern Plains (N=7) *J. virginiana*	
534-6	SD	731-1	NE	534-7	SD	581-3	MT	762-4	KS	534-4	SD	321-3	WY	582-2	MT	782-1	TX		
631-5	SD	731-2	NE	732-2	KS	641-2	NE	762-5	KS			331-3	WY	582-4	MT	841-2	OK		
651-3	NE	731-5	NE	732-4	KS	641-3	NE	762-6	KS			461-1	MT	582-6	MT	841-3	OK		
651-4	NE	751-2	NE	732-6	KS			781-2	KS			461-2	MT	584-7	SD	841-5	OK		
651-5	NE	752-4	KS	751-3	NE			781-4	KS			531-1	MT	585-1	WY	851-1	TX		
652-1	NE	752-5	KS	762-1	KS			781-5	KS			531-4	MT	641-1*	NE	861-2	TX		
652-2	NE	761-2*	KS	762-8	KS			801-1	KS			581-1	MT	671-2	WY	1122-2	OK		
652-3	NE	761-3	KS	1023-3	NE			802-1	OK			582-1	MT	9331-2	WY	652-4	NE		
652-4	NE	761-4	KS	1023-4	NE			1122-1*	KS										
652-5	NE	1023-5	NE	1061-3	NE			1122-5	KS										
661-3	NE	1023-6	NE	1061-4	NE														
661-4	NE	1061-1	KS	1121-4	KS														
661-5*	NE	1061-5	NE																
711-1	NE	1071-1	IA																
711-3	NE	1071-3	IA																
711-4	NE	1072-2	IA																
711-5	NE	1072-3*	IA																
721-3	KS	1121-3	KS																

**Identifies the five sources incorrectly classified by discriminant analysis that were reassigned to new clusters. The single digit numbers following the seed zone number denote individual sources within that zone.*

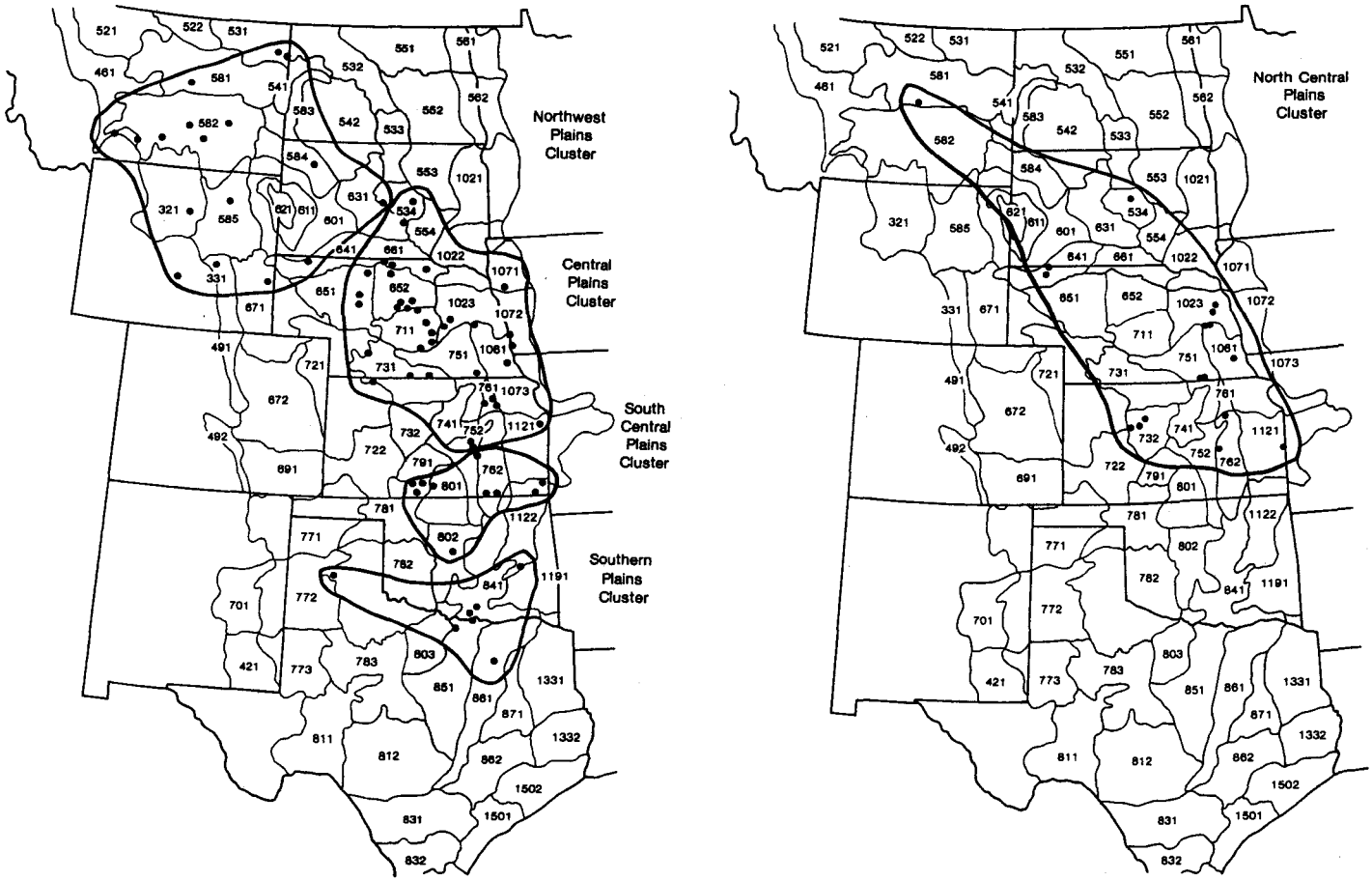

Figure 2.—*Juniperus* height-survival clusters as determined by cluster discriminant analysis. Black dots represent individual seed sources within clusters.

Table 2.—Mean heights (cm) and survival (%) of *Juniperus* seed source clusters as determined by height-survival cluster analysis (see table 1 for source identities per cluster).

Seed source cluster	Northern				North Central		Central				South Central		Southern		$\bar{x}$	
	Towner N. Dak.		Mandan N. Dak.		Brookings S. Dak.		Plattsmouth Nebr.		Hastings Nebr.		Colby Kans.		Big Spring Tex.			
Location	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.	Ht.	Surv.
Central Plains (N = 36)																
$\bar{x}$ Height	97.2		167.3		137.5		227.7		210.3		189.5		76.5		158.0	
$\bar{x}$ Survival		89.7		92.6		93.2		99.4		99.4		87.6		42.2		86.3
North Central Plains (N = 15)																
$\bar{x}$ Height	75.5		154.8		118.1		206.4		190.8		177.8		73.7		142.4	
$\bar{x}$ Survival		82.3		91.3		87.7		98.0		98.7		89.7		55.7		86.2
South Central Plains (N = 10)																
$\bar{x}$ Height	52.8		115.4		86.7		208.4		188.8		146.0		79.1		131.0	
$\bar{x}$ Survival		62.2		60.5		79.0		98.0		97.5		75.0		51.5		74.1
Northwest Plains (N = 17)																
$\bar{x}$ Height	80.0		142.4		108.1		169.8		153.8		158.4		56.6		124.2	
$\bar{x}$ Survival		89.4		86.2		92.4		99.4		98.2		85.9		41.2		84.7
Southern Plains (N = 7)																
$\bar{x}$ Height	26.1		71.3		72.6		165.6		143.5		99.9		67.5		92.3	
$\bar{x}$ Survival		19.3		22.9		40.7		86.4		92.9		55.7		27.9		49.4

in northwest Nebraska (641–2,3) and in central Montana (581–3) (fig. 2). The South Central Plains cluster (131 cm, 74%) was centered in south-central and southeast Kansas. The Northwest Plains cluster (124 cm, 85%), consisted primarily of shorter Montana and Wyoming sources. The cluster of shortest and poorest surviving sources was the Southern Plains cluster (92 cm, 49%), centered in southeast Oklahoma and north-central Texas (fig. 2, table 2).

Considering only the best one-half of the sources in the best Central Plains cluster, the majority occurred in central Nebraska, western Iowa, and north-central Kansas (fig. 3). The best one-half of the sources in the Northwest Plains cluster were concentrated in central to northeast Montana, northwest Nebraska, and southeast Wyoming (fig. 3).

Provenance Transfer Models

In the northern plantations (Towner, ND; Mandan, ND; and Brookings, SD) height was significantly related to differences in latitude and longitude between seed source and plantation location (table 3, fig. 4). In the central plantations (Hastings, NE; Plattsmouth, NE; and Colby, KS) height was significantly related to differences in elevation and latitude between seed source and plantation location. At Big Spring, TX, height was only weakly related to differences in longitude between seed sources and plantation location (table 3).

Attempts were made to combine models across plantations, but models for individual plantations were distinct in every instance (using extra sums of squares principle, $\alpha = 0.05$, Draper and Smith 1981). Significant correlations between survival and the driving variables were not present in the data.

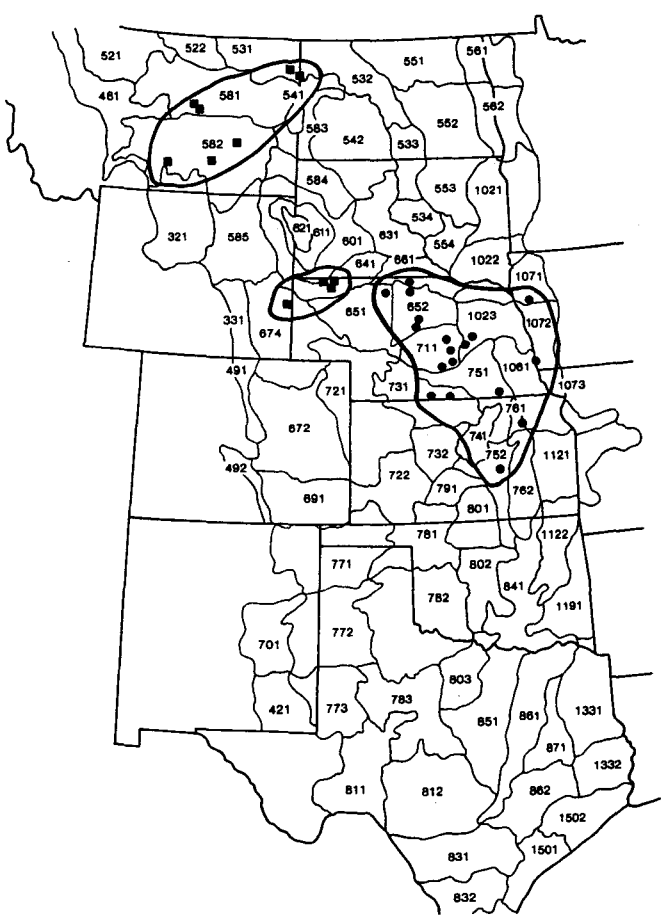

Figure 3.—Geographic areas of tallest *Juniperus* (*J. virginiana* (o) and *J. scopulorum* (□)) seed sources with good survival.

Genotype x Environment Interaction

G x E interaction in tree height was significant ($\alpha < 0.001$) but minimal among the sources in the northern plantations (Towner, Mandan, and Brookings) (fig. 5). In these plantations, sources from the Southern Plains and South Central Plains clusters grew more slowly than sources in the northerly cluster groups. Height growth of sources in the South Central Plains cluster improved in the Nebraska plantations (Plattsmouth and Hastings) but declined again at Colby, KS. All sources performed similarly at the southwestern plantation at Big Spring, TX. Sources from the Southern Plains cluster were among the shortest in all plantations, and sources from the Central and North Central Plains clusters grew tallest in nearly all plantations (fig. 5).

There was significant G x E interaction in survival, with the pattern across plantations being similar to that of height. The main difference was that survival was uniformly high in the Central Plains, North Central Plains, and South Central Plains clusters (fig. 6).

Age/Age Correlations

Seventh-year field heights of 4,000 *Juniperus* trees of 204 seed sources were recorded (fall 1986) in the Hastings plantation. The correlation at age 2 vs. age 7 was $r = 0.90$ when computed at the seed source mean level (table 4), but only 0.71 when computed at the individual tree level. Coefficients computed at the tree level increased to $r = 0.81$, 0.87, and 0.90 for ages 3, 4, and 5 vs. age 7, respectively.

Best Seed Source Locations

Seed zones were identified from which seed produced better surviving and taller trees, at age 5, in plantations throughout the Great Plains; e.g., 651, 652, 661, 711, 731, 751, 752, 761, 1023, 1071, and 1072 in the central and southern plains; 531, 581, 582, 641, and 671 in the northern plains. However, the sources sampled within these zones represented only a portion of the material available. The question arises, If certain seed zones are designated as containing better sources, how often would sources selected in those zones be in the better cluster?

The probability of a source belonging in the Central Plains cluster was estimated for all seed zones represented in that cluster (table 5). For all sources belonging to seed zones represented in the Central Plains cluster, the frequency of occurrence is tabulated for each

Table 3.—Provenance transfer model relating height growth to source location relative to plantation location.

Plantations	R^2	SE[1]	Regression coefficients[2]					
			Constant	ΔLat.	ΔLat.^{2}	ΔLong.	ΔLong.^{2}	ΔElev.^{2}
Towner	0.71	12.6	109.9	—	-0.41	—	-0.26	—
Mandan	0.76	14.9	179.0	—	-0.66	—	-0.33	—
Brookings	0.55	17.8	136.6	—	-0.53	—	-0.60	—
Colby	0.77	14.2	163.6	8.57	-1.28	—	—	-0.01
Hastings	0.68	16.2	203.8	2.31	-1.28	—	—	-0.01
Plattsmouth	0.59	20.7	233.0	—	-1.26	—	—	-0.01
Big Spring	0.33	10.3	68.5	—	—	-1.85	—	—

[1]*Standard error of estimate.*

[2]*Differences between sources and plantations in latitude (negative values represent sources south of plantations); in longitude (negative values represent sources east of plantations); in elevation (negative values represent sources lower than plantations).*

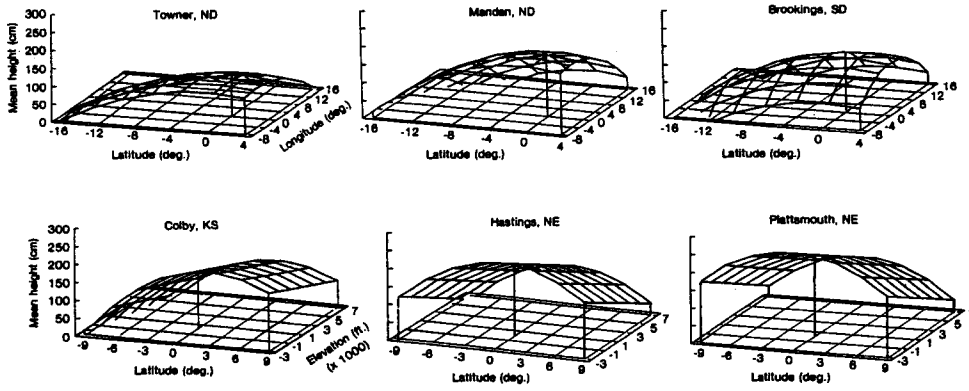

Figure 4.—Provenance transfer models for *Juniperus* plantations. The vertical lines located at (o,o) represented the plantation locations. (See table 3 for definitions of longitude, latitude, and elevation variables.)

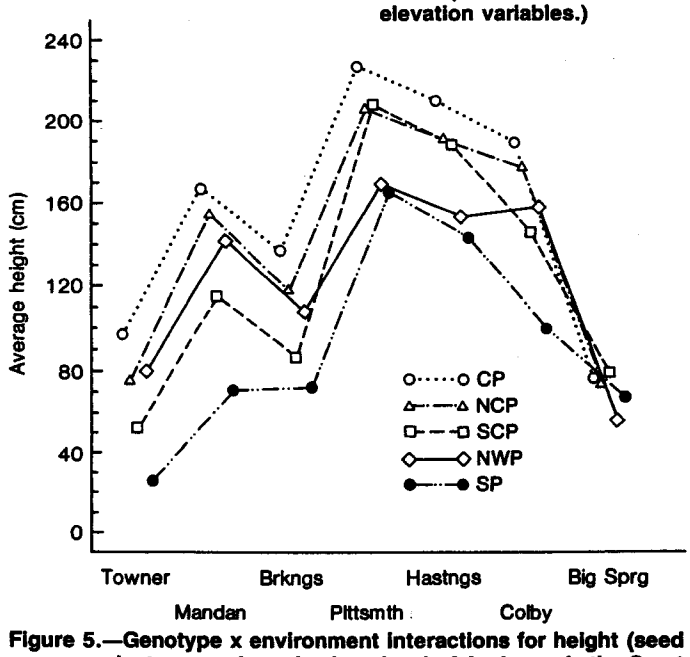

Figure 5.—Genotype x environment interactions for height (seed source clusters vs. plantation locations) of *Juniperus* in the Great Plains. (For each plantation the five clusters are plotted sequentially, from top to bottom [figs. 5 and 6]: Central Plains (CP), North Central Plains (NCP), South Central Plains (SCP), Northwest Plains (NWP), and Southern Plains (SP)).

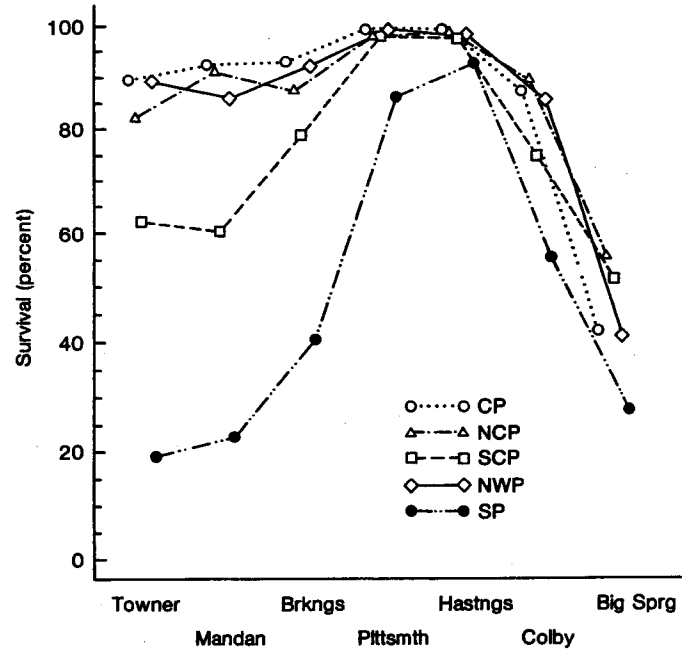

Figure 6.—Genotype x environment interactions for survival (seed source clusters vs. plantation locations) of *Juniperus* in the Great Plains.

Table 4.—Age/age correlations computed at the seed source level among ages 1 to 7 (field age) for 204 seed sources at Hastings, NE plantation.

	Correlations (seed source level)					
Age -----	1	2	3	4	5	7
Year ----	1980	1981	1982	1983	1984	1986
1 1980		0.93	0.88	0.84	0.82	0.77
2 1981			0.97	0.95	0.94	0.90
3 1982				0.98	0.98	0.94
4 1983					0.99	0.97
5 1984						0.97
7 1986						

Table 5.—Frequency of selecting better seed sources within seed zones occurring within best cluster.

Cluster	Frequency	Percent	Cumulative frequency	Cumulative percent
Central Plains	36	80.0	36	80.0
North Central Plains	7	15.6	43	95.6
Northwest Plains	1	2.2	44	97.8
South Central Plains	1	2.2	45	100.0

cluster, providing an index of the practical utility of this set of seed zones.

In the preceding normalized survival-height analysis, 80% of the sources from the sampled seed zones occurred in the "better" Central Plains cluster. Additionally, the North Central Plains cluster was second best; thus, 96% of the sources from the designated seed zones would fall into these two best clusters—the Central Plains and North Central Plains Clusters.

Discussion and Interpretation

The junipers were treated as a single, variable population; however, two species are recognized in Great Plains forestry practice. Because the zone of intermediacy lies between the Northwest Plains and the Central Plains clusters, and for clarity in making recommendations for seed collections, the species names of *J. scopulorum* and *J. virginiana* will be used when referring to sources originating northwest and southeast of this transition zone, respectively.

Provenance Transfer Models

In the northern plantations, sources originating south and west of the plantations performed poorly relative to sources originating north and east of the plantations. However, at Brookings, SD, the heights of sources originating east of the plantation also were reduced. For the central plantations, sources originating lower in elevation than the plantations were taller, and sources originating higher in elevation than the plantations were shorter. The height of sources originating south of the plantations increased more rapidly than sources originating north of the plantations. This north-south gradient decreases in severity moving east from Colby, KS, to Plattsmouth, NE.

Genotype x Environment Interaction

The survival-height clusters derived encompassed sizable geographic areas, and contained relatively large numbers of sources, especially in the Central Plains cluster. Minimal G x E interaction, except at the southern extremities of the Great Plains, indicates that sources within clusters performed similarly in most plantations (figs. 5 and 6). These data suggest the seed zones designated by Cunningham (1975) may be smaller than necessary.

The failure of *J. virginiana* sources from the southern and south-central plains to survive and grow satisfactorily in the northern plains, and the relatively poor survival and growth of the *J. scopulorum* sources from the northwest plains in the southern plains, is attributed to differences between the two environments.

The relative positions of clusters in figure 5 between the Colby (lat. 39°24') and the northern plantations at Brookings (lat. 45°17'), Mandan (lat. 46°49'), and Towner (lat. 48°22') vs. those at the Hastings (lat. 40°30') and Plattsmouth (lat. 41°00') plantations may seem inconsistent. However, the Colby plantation is at a higher elevation in the High Plains region, where environmental conditions more closely resemble those of the northern plantations. There also is similarity in the latitude gradients at Colby, Towner, and Mandan (fig. 4).

Age/Age Correlations

Juniperus grows quickly in height compared to many other coniferous taxa. It, thus, would be desirable to identify sources capable of producing trees of superior height at the earliest age. There is evidence that this can be determined as early as ages 5 to 10 for many conifer species (Lambeth 1980; Lambeth et al. 1983; Nanson 1967; Squillace and Ganzel 1974; Van Haverbeke 1983, 1986a, 1986b). The present analysis indicates trees within sources expressing superior height growth can be detected at age 5, and that sources of superior height growth can be identified by age 2 in the field. This conclusion should, however, be tempered by the availability of data from only one plantation.

Adaptive Differentiation

The genetic diversity demonstrated in this test is interpretable as adaptive differentiation, or variation in response to environmental selectivity. The Great Plains is a large region within which environmental gradients are broad and gentle, with subtle changes. The high survival and good height growth of the *J. virginiana* sources from the central Great Plains region, in most of

the plantations, indicates their adaptability over a wide geographic region. *J. scopulorum* also is adaptable throughout much of the northern and central Great Plains. Thus, it can be expected that a relatively large number of sources from a given area—especially the central plains—could survive and flourish over a wide portion of the Great Plains, as long as the genetic constitutions of the individual trees are able to tolerate the extremes of their new environment. The *Juniperus* species in the Great Plains can be regarded as intermediate to broad in their adaptive mode (Rehfeldt 1984), with gentle clines and differentiation that are difficult to detect except at the extremities.

Best Seed Source Locations and Early Recommendations

These data suggest that *J. virginiana* seed should be collected in east-central Nebraska rather than in west-central Nebraska, as is the current practice. This seed promises to produce trees adapted to a greater portion of the Great Plains. It also should be more uniform than is the current source of seed, located within the transition zone between *J. scopulorum* and *J. virginiana*.

The performance of *J. scopulorum* seed may be improved by collecting seed from the Pine Ridge (Dawes County) region of northwest Nebraska, or central Montana. Such seed should perform well southward through the Great Plains into west-central Kansas, but not east of the 100th meridian where *J. scopulorum* is susceptible to the foliage blight *Cercospora sequoiae* var. *juniperi*.

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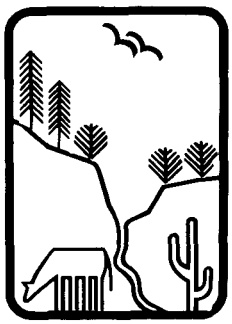
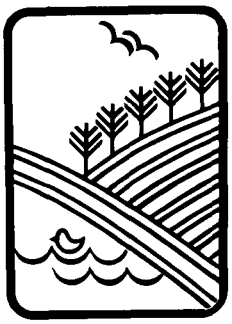
Fifth-year analyses of Great Plains *Juniperus* seed sources indicate eastern redcedar should be collected in east-central Nebraska for use throughout the Great Plains; Rocky Mountain juniper seed should be collected from northwest Nebraska, or central Montana, for planting southward through the Great Plains into west-central Kansas west of the 100th meridian.

Keywords: eastern redcedar, *J. virginiana*, Rocky Mountain juniper, *J. scopulorum*, cluster discriminant analyses, provenance transfer model analyses, genotype x environment interaction, age/age correlation, adaptive differentiation.

Rocky
Mountains



Southwest



Great
Plains

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Rocky Mountain Forest and Range Experiment Station

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