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GENETICS



of EASTERN REDCEDAR



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RESEARCH SUMMARY

Eastern redcedar (*Juniperus virginiana* L.) is a highly variable and widely distributed conifer complex of Central and Eastern United States. It is a versatile tree, well-adapted for growth in a wide range of climatic, edaphic, and topographic situations. It can remain a viable component of understory and openings in other conifer and broadleaf forests, and can also pioneer aggressively into abandoned fields and grazed grasslands. Soils derived from limestones and dolomites provide favorable sites for it.

Multi-character analysis studies in natural populations have provided information on genetic variation, and produced theories on migration and interrelationships among other juniper species especially in the western and central parts of its range. Since interpretations are different and somewhat conflicting, controlled breeding experiments will be needed to test their validity. Population studies are generally lacking in the eastern range.

Staminate and ovulate strobili are borne on separate trees (dioecious), which are easily distinguished in mid-winter by the color and size of branch tips that contain the staminate strobili. Pollination occurs from February (south and east) to May (north and west), and fertilization about a month later. Embryo is full-grown about 2 months after fertilization, and thus the seed matures in one season. Research on reproductive development is mainly from the southern and eastern range of the species.

Seed production is normally abundant every 2 to 3 years, and the juniper cones are extensively used by many species of wildlife. There can be dormancy problems if seed are allowed to dry after collection and extraction, but various scarification and/or stratification methods will overcome these.

Propagation by rooted cuttings and grafting is the common practice of commercial nurseries. The ease

of vegetative propagation and demand for selected cultivars for landscaping purposes are likely reasons for lack of information on sexual methods of propagation.

Controlled breeding in eastern redcedar has been attempted only recently. Viable pollen can be obtained by forcing cut branches in the laboratory or greenhouse, and controlled pollination seed set has been as effective as wind pollination.

A broad delineation of races within the rangewide distribution of eastern redcedar is available from population studies, but considerable research is needed to verify and improve it. A central region in Kentucky, Tennessee and the southern Appalachians, regarded as the type form, is surrounded by populations which have been influenced by other juniper species. As a consequence, the rangewide variability in tree form, foliage color, and many other characteristics is extremely great.

Provenance studies of eastern redcedar are few and contradictory. Foliage color, crown form, and proportion of leaf types were correlated with latitude of origin, and there were differences in susceptibility to cedar-apple rust. In another study, foliage color and proportion of leaf types were not related to seed source and were considered under strong genetic control by individual trees within stands.

Information on disease and insect resistance is mostly lacking. Indications of resistance to cedar blight and to cedar-apple rust were reported on horticultural selections and varieties, but not in natural stands of eastern redcedar. Improvement programs in eastern redcedar are quite recent. Individual tree selection, provenance testing, controlled breeding, progeny testing, and seed orchard establishment are just getting underway.

GENETICS OF EASTERN REDCEDAR

David F. Van Haverbeke and Ralph A. Read¹

INTRODUCTION

Eastern redcedar (*Juniperus virginiana* L.) is an important and useful conifer of wide natural distribution and great genetic diversity. Its wide range of adaptability with minimal care, and the many crown forms and colors available in its natural populations, have made it especially attractive for screening and landscaping purposes, as well as for shelter barriers and wildlife habitat. The commercial nursery trade has developed relatively easy methods of vegetative propagation, and consequently has mass produced many of the selected horticultural varieties.

The commercial users of eastern redcedar have generally harvested the materials available in natural stands and have been less concerned with the genetic improvement of the species. Recently the utilization of eastern redcedar for Christmas trees, especially in the South, has stimulated interest in genetic improvement by sexual methods. Interest in improving eastern redcedar through selection of superior trees and breeding for the windbreak programs in the Great Plains is also fairly recent.

Research in the genetics of eastern redcedar has been limited to studies of variation in natural populations and in developing techniques for asexual propagation. There are very few studies in phenology of fruiting and sexual reproduction. There is essentially no information on breeding methods, controlled pollination techniques, crossability, compatibility, progeny testing, or heritability.

One reason for lack of research in sexual reproduction may be the extremely small size of the re-

productive structures and the small number of seeds per cone. The technical problems associated with working on very small strobili on separate trees, and the necessity of developing special techniques for isolation and pollination, may have made the junipers less attractive for experimental work than many other tree species.

Research on natural populations of *Juniperus virginiana* and relationships with other junipers has been concentrated in the central and western range of the species. This work has clarified considerable detail about morphological characteristics and has contributed substantially to the understanding of genetic variation in the western populations. Similar information on genetic variation for the large eastern part of the range is lacking, except for the work which established the validity of a columnar form, variety *crebra* (Fassett 1943). The excellent work on reproductive development by Ottley (1909) and Mathews (1939) was done in the eastern and southeastern range of the species, but such information is largely lacking for the central and western distribution.

Presumed hybridization and introgression involving *Juniperus virginiana* in natural populations is discussed at length in several papers, but we are aware of no experiments in controlled breeding to establish the validity of these assumptions.

Botanical Description

The genus *Juniperus*, a member of the Cupressaceae, is widely distributed over the Northern Hemisphere temperate zone from the Arctic Circle to Guatemala in the Western Hemisphere, and to south China in the Eastern Hemisphere. One species far separated from all others occurs in the equatorial highlands of Kenya and Ethiopia, East Africa. The junipers, which comprise the third

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largest genus of Coniferales, are often difficult and confusing to identify. There are about 60 described species according to Dallimore and Jackson (1966) and Hall (1961). Approximately 15 species are native to the United States (Harlow and Harrar 1937; Van Dersal 1938b). Species of the genus are placed into three sections, according to Endlicher (1847) and Hall (1961):

Caryocedrus—one species with woody, cupressoid cones.

Oxycedrus—7 to 9 species with fleshy cones, and acicular leaves only.

Sabina—all other species with fleshy cones, and reduced scale-like leaves, in addition to acicular leaves.

The section *Sabina* contains about 30 species, including *Juniperus virginiana*, named presumably from specimens collected in the English Colony of Virginia. All U.S. junipers, with the exception of *J. communis*, are in this section.

Despite the range-wide inherent variability in the species, which will be discussed in another section, *Juniperus virginiana* may be described as a dioecious (rarely monoecious) conifer, with no distinct buds and with three kinds of leaves:

- 1) ternate or opposite, overlapping, closely appressed, acutely tipped, scale-like leaves 3-4mm long, with entire margins (fig. 1,A and 1,C), and with an oval, rarely elliptical, gland (fig. 1,A inset), which is shorter than the distance from the gland to the leaf tip, on the lower surface.

- 2) ternate or opposite, needle-like, acicular (juvenile) leaves 5 to 10 mm long with entire margins (fig. 1,B)

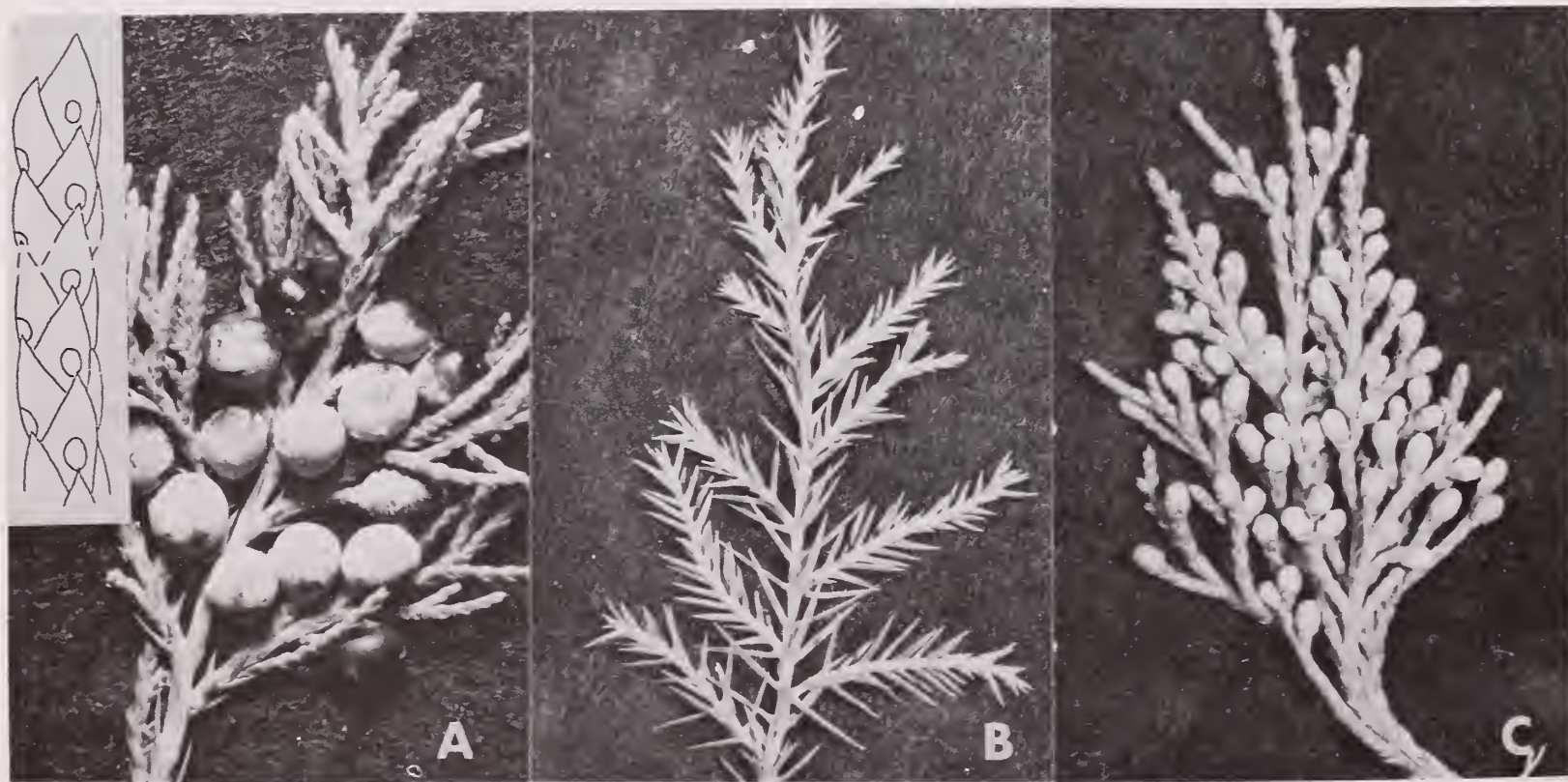
- 3) long shoot whip leaves (not shown).

The fruit is a blue to blue-black fleshy, berry-like cone, 4 to 8 mm diameter, slightly longer than wide, on short, nearly straight peduncles (fig. 1, A). Each cone contains one to three (occasionally up to six) free seeds which mature in one season (Hall 1952a; 1961).

The only distinct varieties described by U.S. investigators are var. *crebra* Fernald (Fernald and Griscom 1935), a narrow, columnar crown form which grows in the Northeastern States, and var. *ambigens* (Fassett 1945), which is an intermediate form between *J. virginiana* and *J. horizontalis*. Dallimore and Jackson (1966) list and describe some 21 cultivars of *J. virginiana*, but there are undoubtedly many more.

Phylogeny

The oldest and most primitive junipers in North America have been found in Upper Cretaceous strata in New England and Greenland. Pollen studies of Pleistocene strata in non-glaciated Eastern United States, however, show no evidence that *Juniperus* was present among the other modern conifer genera, such as *Pinus*, *Abies*, and *Picea* (Whitehead 1965). Evidence of *Juniperus* in the Great Plains region has been found only in most recent, late Wisconsin time, beginning 12,000 to



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Figure 1.—A, Ovulate and C, staminate strobili of *Juniperus virginiana* develop on separate trees; B, foliage consists of acicular (needle-like) juvenile leaves and closely appressed (scale-like) mature leaves (A and C) containing a resin gland (inset 1, A).

13,000 years ago (Watts and Wright 1966). Conifer and broadleaf tree genera are abundantly represented in specimens from upper Cretaceous and Tertiary formations of Western United States (60 million years ago), but there is no evidence of juniper until late Tertiary (Dorf 1936). The arid-land (western) junipers are thus known from the late Pliocene, 1 to 2 million years ago, and in Pleistocene deposits (Hall 1961).

These arid-land junipers may have evolved with development of modern deserts, according to Hall (1952a). Most of the junipers of the world are centered about the Pacific side and are nearly equally divided between Eurasia and America. Hall suggests they could have arisen from a transition Cupressoid which grew in a warm temperate region characterized by winter rains and prolonged summer droughts. Most juniper species have scale leaves and are found in semi-arid regions. The exceptions to this are *J. virginiana* and *J. silicicola*, taller growing trees which occur in more humid climates. These species evidently evolved much later and spread into the more humid eastern regions.

There are many close relations among species of juniper. This suggests much introgression and possibly swamping of genetic differences whenever species ranges meet and hybrid swarms develop (Hall 1961). These swarms may be extensive and exist in nature for a long time.

Several investigators have made population studies which included two or more junipers with overlapping ranges. Eastern redcedar and Rocky Mountain juniper (*J. scopulorum* Sarg.) were studied by Fassett (1944b); Hall (1947, 1952a); Hall and Carr (1968); and Van Haverbeke (1968a). Eastern redcedar and horizontal juniper (*J. horizontalis* Moench.) were studied by Fassett (1945) and by Ross and Duncan (1949). Eastern redcedar and *J. ashei* Buch. were studied by Hall (1952b, 1955); Hall and Carr (1964); and Flake et al. (1969). The *J. virginiana-scopulorum-horizontalis* complex was recently studied by Schurtz (1971).

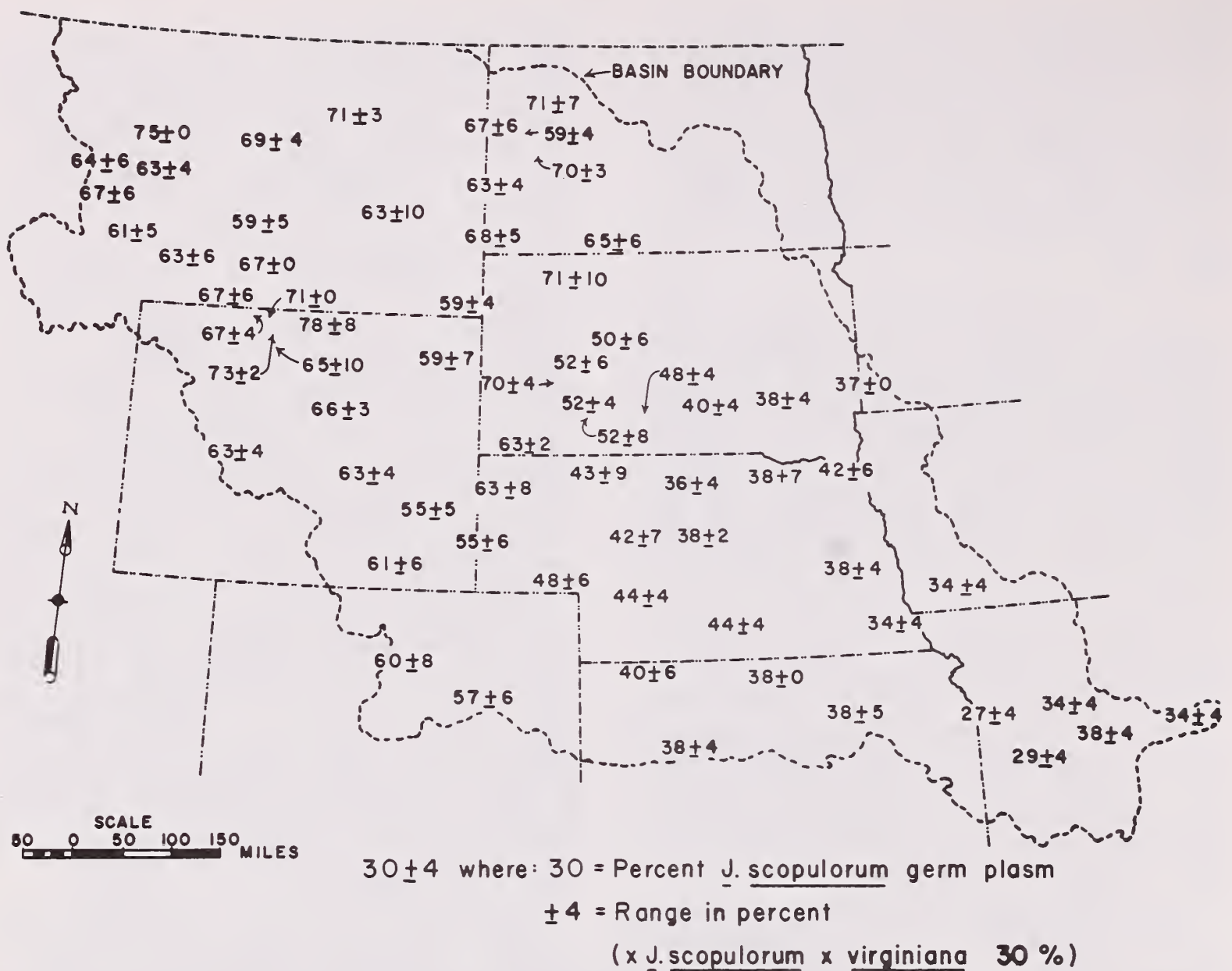
Some investigators have maintained that *J. scopulorum* and *J. silicicola* (southern Coastal Plains) are subspecies of *J. virginiana*, but Hall (1961) feels that the data do not justify this concept. According to Hall, *J. virginiana* apparently hybridizes freely with *J. scopulorum*, *J. silicicola*, and *J. ashei*. He considers the junipers, especially in the Great Plains, as representing the result of interbreeding of two, possibly three species probably during late Pleistocene, when extreme fluctuations in climate favored the extension and overlapping of species ranges.

The variability to be expected in the population complex of *J. virginiana* and *J. scopulorum* is illus-

trated in figure 2 (Van Haverbeke 1968a). The region sampled represents the western portion of the reported *J. virginiana* range and the eastern part of the *J. scopulorum* range. This variation may well be representative of conditions in other sectors of the *J. virginiana* range where introgression with other species has been reported or suspected. Data are expressed in terms of hybrid indices to represent the hypothetical parental type of *J. scopulorum* (100 percent) and *J. virginiana* (0 percent). The geographic array of computed values, based on the midpoint of the range of values calculated at a given sampling point, reveals a trend of increasing hybrid values from the range of *J. virginiana* into the reported range of *J. scopulorum*. A zone of intermediate values, 50+, extends from western Nebraska northeasterly through South Dakota. Values to the east of the zone are predominantly below 50, and identify populations having characteristics approaching the parental type of *J. virginiana*. Values to the west of the zone are predominantly above 50 and identify populations approaching the other parental type, *J. scopulorum*. These data indicate a relatively strong influence of *J. scopulorum* germ plasm in the western portion of the *J. virginiana* population and suggest that the entire population in the region studied is of hybrid origin, since neither extreme parental type was found. In this study, trees sampled from Tennessee most nearly approached the parental type of *J. virginiana*.

This intermediacy of the *J. virginiana* population has most frequently been interpreted as having been caused by hybridization and introgression. Van Haverbeke (1968a) and Schurtz (1971), on the other hand, suggest that the *J. virginiana* population in eastern and central North America may have been derived from the western juniper complex in the Rocky Mountains, especially from *J. scopulorum*.

Van Haverbeke's theory is that, if the western junipers migrated eastward across the Great Plains and into the eastern deniduous forests, they would have found many favorable niches and could have maintained considerable diversity in germ plasm. At the same time, characteristics of the ancestral species would have been retained in the germ plasm, and—when habitats were available that were more similar to those in the Rocky Mountains (e.g., outcrops and river bluffs) than to those in the surrounding plains—the combinations of germ plasm more similar to that of the ancestral species would have been favored. Mirov (1967) has stated that the main pathway of migration of the pines in North America has always been southward and eastward. One might assume that this could apply equally to the junipers, since they are usually associated with the pines in most of the xeric habitats of Western United States.



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Figure 2.—Hybrid indices derived from 24 gross morphological foliage, cone, and seed characters of 303 *Juniperus* trees growing in natural stands in the Missouri River Basin from St. Louis, Mo. to the Continental Divide in western Montana.

Thus, what has commonly been regarded as *J. virginiana* may be interpreted as a divergent gene pool, from which other variants have further diverged to the extent that several specific names have been applied (Schurtz 1971). In short, it is suggested that what has previously been interpreted as hybridization may, in reality, be a record of plant evolution through divergence. When one considers the demonstrated and speculated regions of intermediacy between the "type" and other "species," eastern redcedar is the most widespread of the junipers in the United States.

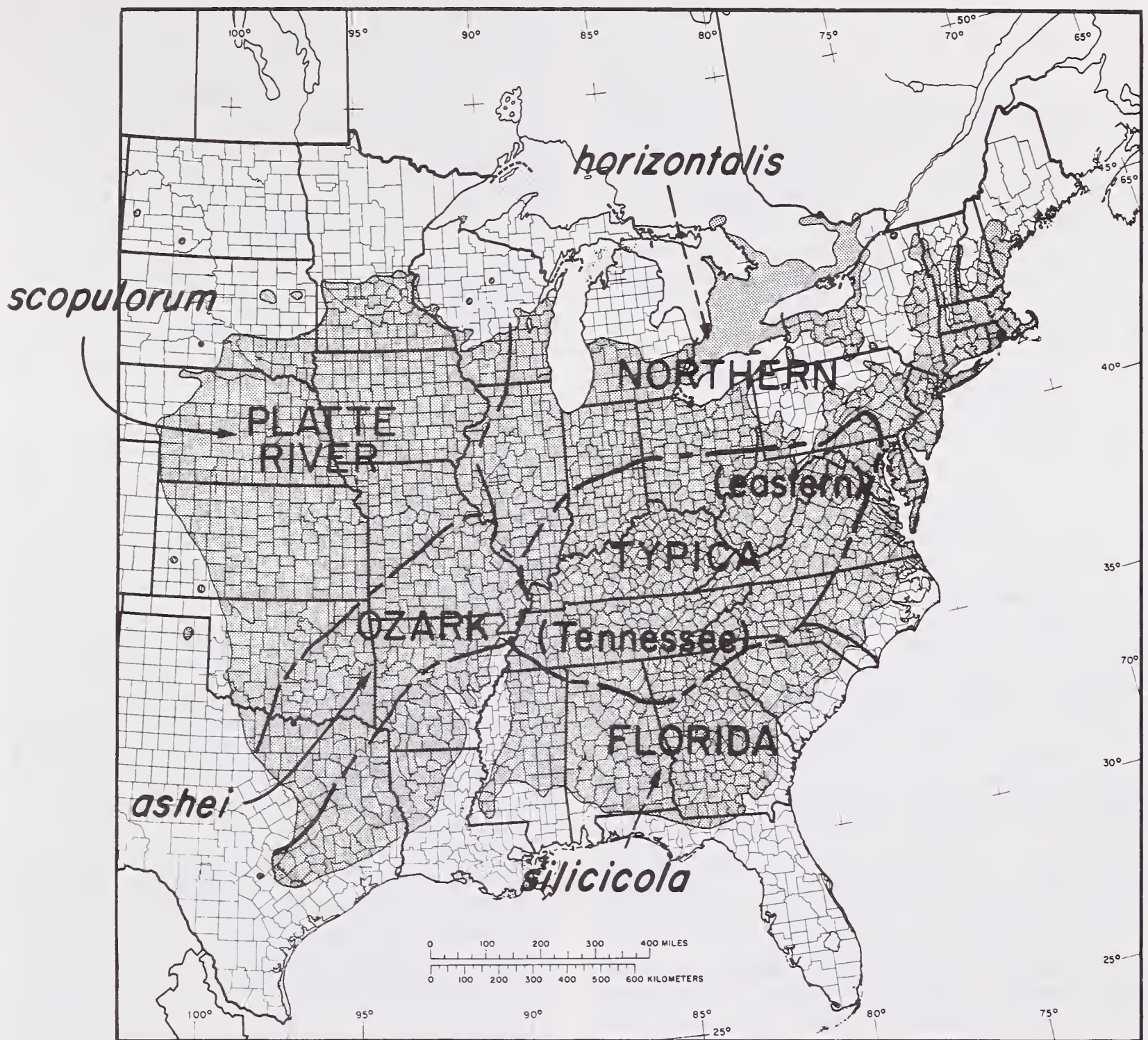
Intermediate forms, but none typical, of *J. virginiana* were found in a complex with *J. scopulorum* in the Texas Panhandle. These forms, in one of the extreme western locations for trees in the *J. virginiana* complex, are characterized by single stems, pyramidal crowns, and very tight gray bark (Hall and Carr 1968).

Man has also selected and propagated, vegetatively as clones, every conceivable kind of juniper

from the vast storehouse of variation existing in nature. Many of these variants could well be hybrids containing genes from three and four species. Frequently, these horticultural forms are grown in such quantities that mutants are occasionally found, and these are propagated as cultivars. Thus, as the result of man's economic and esthetic interest in the junipers, he has further complicated the variation patterns found in nature. Hall (1961) concluded that the taxonomy of the junipers is not adequately known and probably will not be known, until someone is able to look at our "wild species" as a whole and fit the cultivated types into a realistic pattern.

Present Distribution

Eastern redcedar (*Juniperus virginiana* L.) is the most widely distributed conifer of tree size in Eastern United States (fig. 3). It is indigenous in every State east of the 100th meridian and the southern parts of Quebec and Ontario (Williamson 1965).



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Figure 3.—Delineation of races and introgressants (after M. T. Hall, 1952b, pg. 56, Map 3) within the distribution of *Juniperus virginiana* L. (Little 1971).

Distributed over this extensive natural range from 29° to 45° north latitude and from 69° to 102° west longitude, *Juniperus virginiana* is notably adapted to an extremely wide variety of climate, soil, and topography. Annual precipitation ranges from 40.64 cm (16 inches) in the Great Plains to over 152.40 cm (60 inches) in the Southeast. Extremes of temperature range from -40°C in the Central Plains and Minnesota to +46°C in the central and southern Great Plains. The species has withstood January temperatures of -47°C (Parker 1963). Elevation ranges from sea level to over 1524 m (5,000 feet) in western Nebraska and Kansas. The growing season ranges from 120 days in the Dakotas to 250 in the southern Coastal Plains (Williamson 1965).

One implication of such a wide-ranging distribution is that the species will have much genetic variation, resulting in diverse phenotypic variations. This is certainly the case with *J. virginiana*, as will be discussed later.

The species is well known as a “pioneer” in vegetational succession. Present indications are that control of wild fires has allowed *J. virginiana* to occupy many sites within its natural range where it did not previously exist (Beilmann and Brenner 1951a; Hall 1955). In addition, the species range has been considerably extended, especially in the Great Plains, by the many thousands of planted trees which provided seed sources for local dissemination by birds.

Eastern redcedar grows best on deep, moist, well-drained alluvial sites, where its height may reach 18 m in 50 years. Maximum heights of 30 to 37 m for mature trees have been noted. Although it is rather tolerant of shade when young,² it is considered an intolerant species by Baker (1949). Because it grows slowly after reaching 9 m or so, it is not competitive with pine and hardwoods. It thus rarely becomes dominant on good sites (Ferguson et al. 1968). Beilmann and Brenner (1951a) consider it quite shade-tolerant, however, since it can persist in grassland until a favorable opportunity for rapid growth arrives.

The species is most frequently found in pastures, abandoned fields, fence rows, and on rocky outcrops of calcareous parent materials (Ferguson et al. 1968; Williamson 1965). It is common on heavy clay soils in the Piedmont from Virginia to Georgia, mainly in pastures, old fields, and open woodlands.³ In the central and eastern portion of its range, redcedar commonly grows on rocky outcrops of limestone and dolomite (Harper 1912; Collingwood 1938; Albertson 1940; and Hall 1952a). When it occurs as the dominant vegetation type, eastern redcedar often shows a very close relationship to specific geologic strata (Beilmann and Brenner 1951b; Read 1952).

Afanasiev (1949) and Arend and Collins (1949) concluded that depth of soil and drainage are the most important site factors affecting growth. Natural stands of eastern redcedar in the Ozarks grow in soils that vary widely in pH from 4.7 to 7.8 (Arend 1950). The presence of eastern redcedar trees in Connecticut pine plantations, and the specific effects of their leaf litter, brought about significant changes in soil chemical and physical properties (Read and Walker 1950). In the western part of its range, the species is found on north-facing slopes and along streambanks where it is sheltered from heat and drought (Albertson 1940). It is now a fairly common understory tree in the cottonwood and other hardwood types of river bottomlands, especially in the Platte River valley of Nebraska (Stone and Bagley 1961).

Eastern redcedar ranks in the least alkali-tolerant class among drought-hardy species (Stoekeler

1946), but is fairly salt tolerant (Moss 1940). It will succeed in air-polluted areas where many other conifers fail (Bailey 1923). Ferguson et al. (1968) stressed that eastern redcedar is usually the only valuable tree on many shallow soil sites in the Ozark region, where other species grow poorly, and therefore should be favored in timber management on such areas.

Uses

Eastern redcedar trees have been highly valued and sought after since colonial days for both domestic and export uses. The heartwood has outstanding qualities of durability, rich color, aromatic odor, fine and uniform texture, and workability (Williamson 1957).

Merchantable stands of eastern redcedar were formerly abundant from New York to Florida and Mississippi and were scattered throughout the Eastern United States. Its most important use in the early 1900's was for pencils (Betts 1953). The largest remaining commercial stands are in the Ozark Mountains of Arkansas and Missouri, in Tennessee and Kentucky, and in the Carolinas and Virginia. Eastern redcedar sawtimber volume in the United States was estimated at 490 million b.f. in 1953 (U.S. Dep. Agric., For. Serv. 1955).

The major present use of the species in quantity is for fenceposts. This use has reduced the possibilities for sawlog production, which is now of minor economic importance because of limited availability (Hemmerly 1970).

Other uses are for furniture, cedar oil, ornamentals, shelterbelts, Christmas trees, woodenware, novelties, kindling, and shavings. Cedar chests and closet linings are two favored uses of the highly aromatic heartwood, which reputedly discourages moths. Fruits, young foliage, and wood contain aromatic oils used in medicine, perfumes, and the manufacture of alcohol (U.S. Dep. Agric., For. Serv. 1974; Betts 1953). The species is important throughout the South for Christmas trees (Sowder 1966). Horticultural selections of it, derived from 18 or more varieties, are commonly used for ornamentals in the nursery trade. The species is extensively used in shelterbelt and windbreak plantings throughout the Great Plains (Read 1964), and as wildlife food and cover (Read 1948; Van Dersal 1938a).

²This statement is based on our observations in shelterbelts and river lowlands of the Great Plains.

³R. E. Schoenike, personal communication, Feb. 1972.

SEXUAL REPRODUCTION

Reproductive Development

Eastern redcedar is a dioecious species. Staminate (male) conelet development has been observed on 4- to 5-year-old trees, but no information was found on the starting age for ovulate (female) conelet production. Sexual maturity is probably not reached until at least 10 years, after which fruiting occurs annually.

Conelets begin to develop on staminate trees at the tips of axillary branches of new scale-leaves. They become conspicuous in early fall (fig. 1,C). The staminate conelet has 10 to 12 entire-margined sporophylls with blunt apices. Pollen grains are formed by late September. Staminate strobili are yellowish brown; therefore, when they attain mature size during winter, staminate trees are easily distinguished from ovulate trees. When meiosis is completed, strobili pass the winter filled with mature microspores (Mathews 1939).

Small green conelets begin to develop on ovulate trees during September in Chapel Hill, N. C., for example, but growth is slight during winter. They are borne terminally on axillary branches of the new scale-leaves, but are not recognizable to the naked eye until about the time of pollination the following spring (Mathews 1939). Ovulate conelets on redcedar in the Ozarks are evident in late February (Hall 1952a).

The microsporangial walls of staminate conelets split longitudinally in late winter and early spring, discharging the mature pollen. Pollen grains become lodged in the pollination drop at the end of the micropyle of the many ovules in the conelet. Conelet scales close after a few days, completing pollination (Hall 1947).

Early growth of the pollen tube is slow. Growth becomes active and direct by the last of May or mid-June, when the pollen tube penetrates to the necks of the archegonia within a few days (Mathews 1939). Fertilization occurs in June when the two sperm nuclei fertilize the eggs, usually in two archegonia. Cleavage polyembryony occurs, and several embryos develop in a single archegonium. One of the anterior embryos develops more rapidly than the others, and becomes the mature embryo of the seed (Hall 1947). The mature embryo is full-grown about 2 months after fertilization, late July to mid-November, depending on location. Thus, the seed matures in one growing season.

In development of the ovulate cone, one or two fruit-scales arise on the upper side of each of the four (3 to 8) megasporophylls, and a separate vascular bundle develops for each. These greenish fruit-scales continue to grow upward and coalesce above

the ovule to produce the outer fleshy coat of the berry-like cone. Color of cones changes through the season from green to greenish-white to whitish-blue to glaucous blue. The white of young fruits is very conspicuous in early to mid-summer in the Carolinas.⁴ The mature cone has a strong integumentary layer which forms a protective coat entirely surrounding the seed.

The one to three (or more) seeds in each cone are 2 to 4 mm in length, are rounded or variously angled, and often have longitudinal pits. Two-seeded cones predominate in the northern part of the range of the species (Hall 1952a). The seed coat has two layers, the outer thick and bony, the inner thin and membranous. The embryo is straight and contains 2 cotyledons.

Ross and Duncan (1949) studied somatic chromosome complements in *J. virginiana* L., *J. horizontalis* Moench, and their hybrids during meiosis in pollen mother cells. They reported a higher frequency, 57 percent, of irregularities as heterobrachial chromosomes without counterparts in the hybrids, as compared to 2 percent or less in the parental species. In spite of these irregularities, the somatic chromosome number of both species and their hybrids was $2n = 22$. The diploid chromosome number of most if not all members of *Juniperus* is 22 (Sax and Sax 1933; Love and Love 1948; Khoshoo 1961).

Hall (1961) reported there is almost no significant karyotype differentiation in *Juniperus*. The chromosomes are so similar that crossing is possible between most species, at least within the sections. The evidences of clinal distributions, hybridization, introgression, and evolutionary divergence reported among the many populations of *Juniperus* tend to support the view that there are no serious meiotic irregularities within the genus.

Polyploid seedlings have been reported in the Coniferales, but polyploidy is rare, only 1.5 percent (Khoshoo 1959). Stiff (1951) reported a naturally occurring triploid ($3n = 33$) staminate individual of *J. virginiana*. Khoshoo (1959) also reported an instance of a polyploid *J. virginiana* tree. Because of poor growth and infertility, however, polyploidy is likely to be unrewarding as a means for improving conifers, including *J. virginiana*.

Pollination

Pollination occurs from mid-February to mid-May (Jack 1893), depending on geographic location. In the Ozarks it is in early March and in Nebraska from

⁴ R. E. Schoenike, personal communication, Feb. 1972.

mid-March to mid-May (U.S. Dep. Agric., For. Serv. 1974). Fruiting, pollination, fertilization, and cone ripening are approximately 1 month later in New England than in Texas (Hall 1952a). Seasonal variation in pollination may be 2 weeks in Massachusetts (Ottley 1909). Pollen is very light and dispersed by wind, but no information is available on dispersal distances.

Djavanshir and Fechner (1975) found that *J. virginiana* pollen forced by bringing branch tips into the laboratory germinated better and had greater pollen tube growth than pollen extracted at collection time. October and November collections were generally too early, but December through March collections yielded 30 to 90 percent germination, respectively, for forced pollen. Pollen germination began in 3 to 5 days after culturing, and tube growth reached maximum in about 16 days. Best medium for germination and growth was 10 percent (W/v) sucrose plus 0.5 percent agar. Storage up to 3 months at 4° to 6°C did not affect germination and tube growth of either forced or extracted pollen.

Only very recent information was found on controlled pollination of *J. virginiana* or any other juniper. The many phenotypic variants available in natural stands and the ease with which they are vegetatively propagated has evidently satisfied the past needs of the commercial trade. Pollen from branches collected as early as December 31 and forced to mature in the laboratory was as effective as fresh (March) pollen in obtaining controlled pollination seed set in *J. virginiana*, and this was as effective as wind pollination (Fechner 1975).

Controlled breeding of eastern redcedar may require some modification of conventional techniques. Isolation of staminate strobili for collection of pollen—as well as isolation and pollination of ovulate strobili by entire branches rather than as individual cones—may be necessary. Bagging or building a chamber around an entire tree may also be feasible.

Seed Production and Germination

Good seed crops occur every 2 to 3 years, with light crops intervening. Seed production begins at about 10 years and continues up to 175 years, with optimum production between 25 and 75 years. There is a large range in seed size; number of cleaned seeds per kilogram ranges from 99,000 to 147,000 (U.S. Dep. Agric., For. Serv. 1974).

Seed are widely dispersed by birds (Phillips 1910) and to some extent by deer browsing. Seventy wildlife species are reported to use redcedar for food

and cover, which may be the widest use of any woody plant in North America (Van Dersal 1938a).

Eastern redcedar cones are mature in the central part of its range by mid-September, when they begin to turn dark blue to black. Cones are collected by hand stripping, picking, shaking, or flailing the branches over canvas. Seeds are commonly cleaned by first soaking the cones in water for several days to soften and loosen the pulp, next rolling the seeds on a flat surface, then floating off the pulp and unsound seeds in water (Afanasiev and Cress 1942). Cones can also be depulped in a hammermill (Webster and Ratliffe 1942) or by running them with water through a macerator (Stoekeler and Slabaugh 1965; Wycoff 1964).

Eastern redcedar seed of Nebraska origins will germinate successfully if cleaned immediately after collection and sowed moist, without allowing the seed surface to dry (Meines 1965). Seed that have been dried and stored, however, must usually be treated to insure prompt and uniform germination. Under natural conditions, seed normally germinate in spring of the second year following maturity, but some may germinate the first and third years. Embryo dormancy and an impermeable seedcoat are said to delay germination (Pack 1921; U.S. Dep. Agric., For. Serv. 1974).

After seeds are allowed to dry, they can break dormancy only when the seedcoat is made permeable to moisture. Meines (1965) found that stratification in a moist medium at room temperature for a period up to 6 months was more satisfactory than any scarification method. He obtained best germination by sowing the seeds in July or August after the radicles appeared while in stratification. He stressed the importance of never letting the seeds dry, once stratification had begun.

Afanasiev and Cress (1942), on the other hand, found that 10° C was the optimum stratification temperature for eastern redcedar seeds. Germination was retarded at temperatures above 21° C and below 4° C. Scarification and stratification procedures for eastern redcedar seeds have encompassed a wide range of methods, details of which can be found in "Seeds of Woody Plants in the United States" (U.S. Dep. Agric., For. Serv. 1974).

It is quite likely that germination variability is at least partly due to the extreme variability in genotypes over the wide range of natural distribution. A successful technique for seed from one locality may not necessarily be the best for seed from another locality.

ASEXUAL REPRODUCTION

Eastern redcedar does not reproduce by sprouting or suckering (Arend 1950). In some areas of the South, however, eastern redcedar Christmas trees are apparently propagated from vigorous basal branches after the main stem has been cut.⁵ Reproduction by layering is also possible (Arend 1950), but is difficult and not widely practiced.

Rooted Cuttings

Eastern redcedar can be propagated by rooted cuttings, but there is much variability between varieties (and possibly clones) within the species as to ease of rooting. For example, within the species of *J. virginiana*, Mahlstedt and Haber (1957) list the cultivars *pyramidalis* (pyramid juniper) and *schottii* (Schott juniper) as being commonly propagated by cuttings. On the other hand, they list *canaertii* (Canaert juniper), *cupressifolia* (hillfire juniper), *glauca* (blue juniper), and *hillii* (Dundee juniper) as being commonly propagated by grafting. Thus, not only species within the genus, but varieties and cultivars within the species also may be propagated by cuttings, grafting, or both—depending on how easily they root. Yerkes (1945) stated that cuttings of some forms of juniper may require 6 to 8 months to root. Others may require up to 2 years to root. Mahlstedt and Haber (1957) reported that cuttings with a 2-year heel (callous) produced the best root systems.

Snyder (1954) found that November through February was the best time to take cuttings, and that junipers which are difficult to root are greatly benefited by a root-inducing substance. Doran (1952) found that cuttings of redcedar taken in late September rooted 27 percent without treatment, 38 percent with indolebutyric acid (IBA), and 83 percent with a mixture of IBA and Phygon XL talc. Doran (1957) had no success in rooting untreated cuttings of *J. virginiana* cv. *glauca* taken in mid-December, but reported 92 percent success after cuttings were treated with IBA. Box and Beech (1968) found that a 5-second dip in IBA and naphthalene acetic acid (NAA) produced 82 percent rooted cuttings vs. 55 percent for untreated cuttings.

Grafting

Because of the difficulties and inconsistencies in rooting juniper cuttings, grafting has long been the standard method of propagating clonal material of *Juniperus virginiana* (Westervelt and Keen 1960). The usual technique involves matching cambial tissue of a cutting (scion) from a selected clone with

cambial tissue on the stem of a potted seedling, as close to the soil line of the rootstock as possible. A side graft is commonly used (Mahlstedt and Haber 1957). Grafting is usually done in the greenhouse on 2-year-old rootstock during late fall through winter. About 3 months are required for callousing and healing of the graft union. Grafted plants are kept in the greenhouse until the following spring and are then either transplanted to the field or placed in a lath house for 1 year prior to field planting.

Eastern redcedar scions are commonly grafted onto rootstock of eastern redcedar, but Hill (1953) and Ealy (1958) preferred Hetz juniper (*J. chinensis* cv. *Hetzii*) as rootstock, because it stimulated growth in the scions. Also the root system of the Hetz juniper is less variable, more uniformly fibrous, and less subject to Phomopsis blight, a troublesome disease on eastern redcedar rootstock in the humid greenhouse environment.

Pinney (1970) eliminated risk of water entering the graft unions, which would prevent callousing, by burying newly grafted plants in saturated pots to the top of the union in moist peat at 21°C., watering greenhouse floors, and syringing tops of plants through mist nozzles to maintain 100 percent humidity.

Ramets from selected ortets can also be reproduced vegetatively by grafting scions onto unrooted cuttings (Keen 1951; Buckley 1957). Rootstock cuttings are taken from individuals or varieties known for their rooting habit and ease of rooting, and the scion is attached to the unrooted cutting by means of a side graft (Westervelt and Keen 1960; Wagner 1967).

Dipping cutting-grafts in growth-promoting hormones (IBA) and mixtures of fungicides and hormones has generally increased rooting percentages (Ealy 1960; Lanphear and Meahl 1963; Elk 1967). While acceptable rooting percentages have been achieved by grafting scions onto unrooted cutting-rootstock, Westervelt and Keen (1960) report that less height growth and lower survival, at least during the first year, can be expected in field plantings.

Grafting onto potted or cutting-rootstock is usually done in late fall or winter (Elk 1967). Lanphear and Meahl (1966) reported that non-winter-hardened *Juniperus* cuttings taken from stock plants kept in the greenhouse during October to January rooted well. The main requirement for optimum rooting is that materials be subjected to a cold winter-hardening period before propagation. Westervelt and Keen (1960) found that rates of healing and rooting of cutting grafts were much higher—requiring about 97 days in the propagating bench in early winter—after rootstock plants were subjected to a freeze (−3°C) in November.

⁵R. E. Schoenike, personal communication, Feb. 1972.

GENETIC VARIATION

The previous discussion on Phylogeny emphasized the extreme variability in the genus *Juniperus*. Variation within *J. virginiana* is often more conspicuous, but never as constant as the differences among species (Fassett 1944a).

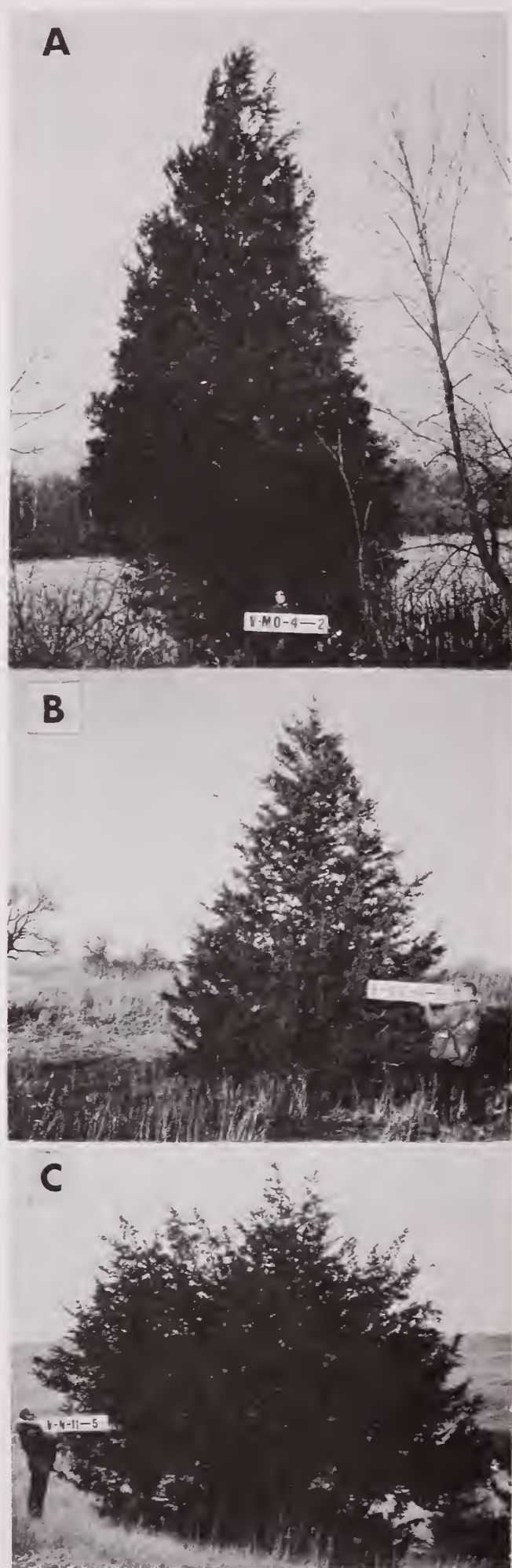
Hall (1952a) proposed a delineation of races in *J. virginiana* based on measurements of a number of characters on individual trees in stands from Texas, Oklahoma, and Nebraska eastward through the natural range to North Carolina, Virginia, and Ontario. These are shown superimposed on the distribution map (fig. 3). He delineated a Typica race which covers the central range in the Appalachian Plateaus and the Interior Lowlands west of the Appalachians. This race was subdivided into two forms: the Eastern, a very tall, narrowly pyramidal tree which occurs in the Appalachians, Interior Plateaus, and Central Lowlands; and the Tennessee, a diminutive form of the Eastern, occurring on limestone glades and barrens of the Interior Plateaus and Nashville Basin. There appear to be four other races associated with and influenced by other juniper species: Ozark containing *J. ashei*; Platte River containing *J. scopulorum*; Florida containing *J. silicicola*; and Northern containing *J. horizontalis*. He emphasizes the fact that these races are not clearly defined, and that since *J. virginiana* is apparently a rather young complex, it is in the process of change.

Van Haverbeke (1968a) sampled intensively in the western part of the range of *J. virginiana*, and suggested that variation in that region is clinally distributed. The transition in tree form from Missouri westward is illustrated in figure 4. Beginning near the Missouri River in northeast Kansas, and westward out the Platte River Valley through central Nebraska and into Wyoming, there is a pattern of gradually increasing hybrid index values (fig. 2). This exceptionally consistent clinal series through one population into another follows primarily along a major water drainage, where changes in the selective intensity of the environment would tend to be more gradual than changes on upland sites with more variable and extreme environments.

Flake et al. (1969) examined the terpenoids of individual trees of eastern redcedar at 150-mile

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Figure 4.—Morphology of eastern redcedar (*Juniperus virginiana* L.) varies greatly throughout its extensive natural range; **A**, Missouri tree, contains many of the morphological characteristics associated with the species in easterly locations; **C**, Nebraska tree is representative of the species in the western portion of its range; **B**, South Dakota tree has intermediate characteristics.



Character Variation

intervals along a 1,500-mile transect from north-eastern Texas to Washington, D.C. They analyzed the data by numerical classification methods, and concluded that *Juniperus virginiana* populations cluster clinally from northeast to southwest. They found the most homogeneous populations in the Appalachians, and the more divergent populations at greater distances from the transect. They found no biochemical evidence to support Hall's (1952a) conclusion that hybridization with *J. ashei* in the Ozarks, and subsequent introgression, have influenced *J. virginiana* populations even as far east as Georgia. They support Barber and Jackson (1957) in suggesting that *J. virginiana* has formed or is in the process of forming regional races, by means of adaptational mechanisms within its own gene pool, and is not being influenced by other junipers.

Thus, the explanations for genetic variability within the *J. virginiana* complex differ according to the types of data analyzed. The evidence for divergence and introgression involving races derived from *J. scopulorum* and *J. asheii* seems to be quite substantial, while the evidence for races derived from *J. horizontalis* and *J. silicicola* is still in the form of a working hypothesis.

The selection and propagation of *J. virginiana* by horticulturists and nurserymen has produced a long list of cultivars, and many of these are standard ornamentals in the nursery trade (table 1).

Table 1.—Common ornamental cultivars (nursery varieties) of *Juniperus virginiana* used in nursery trade ¹

Green-Leaved trees	
<i>canaertii</i>	Canaert ex Seneclauze
<i>crebra</i>	Fernald and Griscom
<i>cupressifolia</i>	Kammerer
<i>hillii</i>	Hill
<i>pendula</i>	Carrière or Lawson
<i>pyramidalis</i>	Carrière
<i>pyramidiformis</i>	D. Hill
<i>schottii</i>	Gordon
Glaucous-Leaved trees	
<i>burkii</i>	Bobbink and Atkins ex Slavin
<i>glauca</i>	Carrière
<i>venusta</i>	(Ellw. & Barry) Rehder
Variegated-Leaved trees	
<i>albo-spica</i>	Beissner
<i>aureo-spica</i>	Hesse ex Beissner
<i>elegantissima</i>	Hochstetter
<i>plumosa</i>	Rehder
Shrubs	
<i>ambigens</i>	Fassett
<i>chamberlainii</i>	Carrière
<i>dumosa</i>	Carrière
<i>filifera</i>	D. Hill
<i>globosa</i>	Beissner
<i>kosteri</i>	Beissner
<i>reptans</i>	Beissner
<i>tripartita</i>	Seneclauze

¹Hall (1961); Dallimore and Jackson (1966).

Variation in foliage morphology as well as chemical differences in the terpenoids of foliage and cones are strongly evident in individual trees of the *J. virginiana* complex. Various methods have been used in attempts to relate these variations to geographic races and clines.

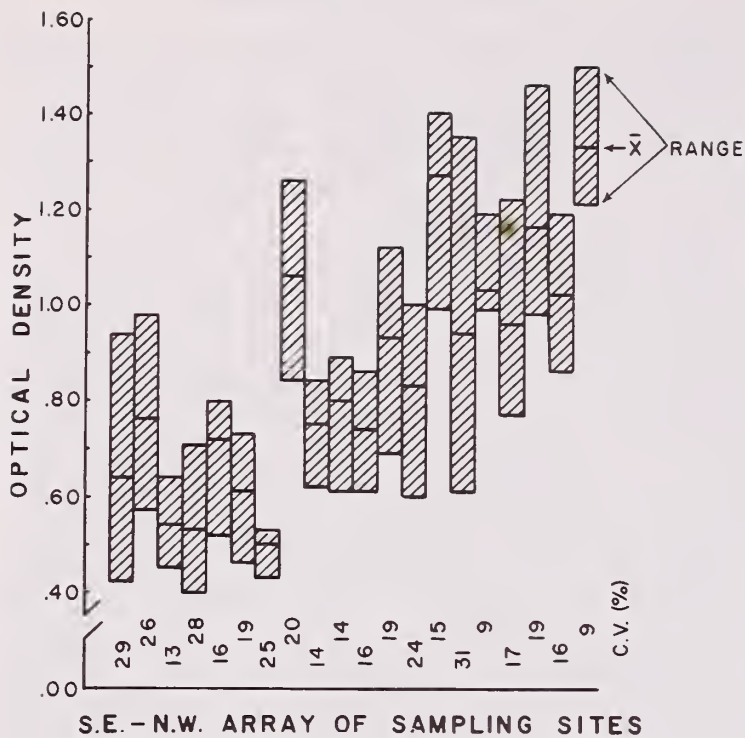
Hall's extensive studies of the species have relied chiefly on pictorialized scatter diagrams comparing two characters at a time. Characters such as leaf gland length-width ratio, whip leaf length, length of terminal and lateral whips, percent of decussate spur shoots on the secondary shoot, and leaf margins entire or denticulate have been used. Foliage color, density, and manner of branching are also used.

Van Haverbeke utilized frequency distributions to show character variations and also subjected all data to multiple correlation analysis, ultimately deriving hybrid index values by statistical analysis. He showed that character variation is very prominent in *J. virginiana*, and since nearly all characters are quantitative, this variation requires statistical treatment for interpretation. In addition to 10 gross morphological characters, 10 foliage characters, and 7 cone and seed characters, he used chemical data from the cone pulp.

An array from Missouri (southeast) to central Montana (northwest) of chemical character data, derived from infrared analysis of cone pulp extract, reflects a directional cline of increasing optical density (fig. 5) (Van Haverbeke et al. 1968). This was especially evident at several wavelengths, but no qualitative evaluation was made of the specific compounds involved. Nevertheless, the data correlate strongly with morphological data from the same trees. Mean optical densities for locations and the ranges of individual tree values reveal considerable overlap, however. These data further illustrate the variability inherent in most biological populations, and emphasize the risk of depending upon only one or even a few metrically expressed characters for positive identification of parental species or their hybrids.

Comparable evidence of character variation in *Juniperus* has been reported by other investigators (Hall and Carr 1964; Vasek and Scora 1967; Adams 1971). Vasek and Scora (1967) concluded that as many characters as possible must be utilized to describe and identify individuals adequately as to species.

Over much of its range, eastern redcedar foliage color apparently changes in fall to brown or purple, or some degree of purplish-red. Color change in Missouri is more pronounced on the acicular than on scale leaves. A study with 1-year-old redcedar seedlings (of Missouri origin) subjected to three levels of light intensity and fertilizer treatments showed no



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Figure 5.—Geographic array of optical density of cone pulp extract illustrates the inherent variability in the *Juniperus virginiana* complex at the character level. (Four or more trees were sampled at each site.)

significant effects of fertilizers, but highly significant effects of light on winter foliage color (Fletcher and Ochrymowych 1955). High light intensity (full sunlight) with lower temperatures and dormancy evidently causes the change to red or purple. Under one-tenth full sunlight, foliage color remained blue-green. Genetic variation, however, is expressed in wild stands: individual trees growing side by side on the same site may differ markedly in degree of winter red and yellow coloration. It was observed that ovulate trees were consistently greener in winter than staminate trees of comparable size on the same site. Foliage of ovulate trees was higher in potassium and calcium than foliage of staminate trees in late fall (McDermott and Fletcher 1955).

Provenance Studies

Minckler and Ryker (1959) evaluated trees in an eight-source (seven State) *J. virginiana* geographic seed test in southern Illinois, after 6 years in the field from 2+0 stock. They observed consistent and wide genetic variation among the replicated source progenies. A source from Tennessee was reported to be superior in size (height and crown volume), winter foliage color, crown shape, vigor, and leaf form. While the number of sources was small and did

not adequately sample the species range, the authors concluded that certain characteristics tended to be correlated with latitude. Foliage was greenest, crowns more broadly conical, and leaves predominantly appressed and scale-like in the southerly and easterly sources, while trees from western and northern sources were brownest in winter, had more slender crown form, and more acicular leaves. Pronounced differences were also noted in susceptibility to cedar-apple rust (*Gymnosporangium* sp.).

A wide range of inherent variation was observed after 5 years in a test of nine seed sources of *J. virginiana* in southwest Missouri (Seidel and Watt 1969). Although a non-local source from West Virginia had better survival, form, vigor, and height growth, the authors concluded that, until the sources had been more fully evaluated, seedlings grown from local seed should be used for planting in the Ozark region.

A replicated study of 21 seed sources, which sampled the extremes of the *J. virginiana* range, was established in South Carolina in 1965 (Schoenike 1969). Preliminary analysis suggests that western and northern sources grow more slowly than southern and eastern sources, and that three sources (at least regionally local)—representing the South Carolina Piedmont, the North Carolina Piedmont, and Virginia—are best adapted to the South Carolina Piedmont. Two characteristics, winter foliage color and proportion of juvenile foliage, lacked any pattern with respect to seed source, and these were suggested as being under strong genetic control by individual trees within stands. The Connecticut and South Carolina sources showed distinctly different characteristics from most others in the study. Schoenike's (1969) preliminary results were reaffirmed after three additional seasons.⁶

In a recently established test of 20 seed sources of eastern redcedar in Nebraska, northern sources (South Dakota, Michigan, Wisconsin, and Nebraska) are suffering less winter injury and are surviving better than the southern sources (Oklahoma, Missouri, and Kansas) (Janssen 1972).

Open-pollinated seeds were collected in west-central Nebraska from a presumed natural hybrid between \times *Juniperus virginiana* \times *J. scopulorum* \times *J. horizontalis*, and seedlings were planted in an observation plot in Nebraska.⁷ These seedlings have shown a wide range of phenotypes and morphological characteristics that indicate a segregating population of hybrid origin.

⁶Roland E. Schoenike, Personal communication, Feb. 1972.

⁷Glenn Viehmeyer, plant breeder (dec.) Dep. of Hortic. University of Nebraska, North Platte, personal correspondence.

RESISTANCE TO DISEASES

Eastern redcedar, despite its adaptability and hardiness, is susceptible to serious injury from leaf blights, leaf and stem rusts, and root diseases (Hepting 1971). Cedar blight (*Phomopsis juniperovora* Hahn) and Cercospora blight (*Cercospora sequoia* Ell. & Ev.) are the two most serious diseases on seedlings in the nursery (Hodges 1975; Peterson 1975). *Phomopsis* kills seedlings as infection spreads from the top downward and outward. *Cercospora* blight, in contrast, begins with browning of the oldest and lowest foliage and proceeds upward and outward, leaving only the green tips in the advanced stages (Hodges 1975). *Cercospora* is severe on older trees in the field (Peterson and Wysong 1968), while *Phomopsis* is not serious on trees over 4 years old (Hahn et al. 1917).

Evidence of resistance to cedar blight has been reported on horticultural selections of *J. virginiana* (Schoeneweiss 1969), but no instances of resistance to these blights have been reported in natural stands.

Cedar-apple rust (*Gymnosporangium juniperi-virginianae*) on eastern redcedar is not normally severe, but it can retard growth and occasionally kill trees by repeated attacks. High resistance to this

disease was reported for individual trees of *J. virginiana* in a West Virginia grove, and in a clone propagated by grafting from one of these (Berg 1940). Resistance to the cedar-apple and cedar-hawthorn rust was evaluated on all junipers at the Morton Arboretum in northern Illinois in 1959 and 1960 (Himelick and Neely 1960). The *J. virginiana* group, with some 26 horticultural varieties and forms, is predominantly susceptible to these rusts. However, resistance is reported for the following varieties and forms at either Morton or Arnold Arboretums:

- var. *aurea*
- var. *burkii* Bailey
 - f. *globosa* (Beiss.) Schn.
 - f. *kosteri* (Beiss.) Lipa
 - f. " *horizontalis* Arb. Kew.
 - f. *plumosa* Schn.

- var. *pseudocupressus*
 - f. *pyramidalis* (Carr.) Beiss.
 - f. " *glauca*
 - f. *tripartita* (Senecl.) Beiss.
 - f. *venusta* (Ellw. & Barry) Rehd.
- Berg's strain—West Virginia

IMPROVEMENT PROGRAMS

The presence and usefulness of eastern redcedar has been taken for granted, with practically no thought toward genetic improvement as a forest tree. The high-quality sawlog trees, in great demand for domestic and export use, were harvested long ago. Young stands have been sought chiefly for fence posts, which has not only reduced the possibilities for future sawlog production, but has also likely removed the better genetic materials from stands. The natural characteristics of existing stands have evidently been so highly desirable that industry has not seriously attempted to increase quality, but has simply high-graded for quantity.

The use of this species in the ornamental nursery trade is quite a different story, however. The desirable qualities of individual trees, such as good color, form, and cone production, have been preserved and perpetuated widely by exploiting the ease of vegetative propagation. Such programs were begun a century ago, by commercial nurseries for the most part, and will continue as the demand for ornamentals increases.

The needs for better Christmas tree materials are not satisfied by the usual asexual propagation methods of the commercial nursery trade, because of the physical limitations and costs involved for

mass production. This new interest may be the fortuitous occurrence which will stimulate studies in genetic variation and sexual propagation for other products, such as wood for cabinet, furniture, and interior use, and for chemical derivatives of the cones and foliage. The objectives of a tree improvement program for the species will, of necessity, be dictated by the intended uses of the tree.

Polk (1964) proposed that quality of eastern redcedar for Christmas trees could be improved through selection of seed parents and through selective breeding of proven trees. The widespread variability within the species suggests that selection of individual trees from local stands would result in substantial improvement (Schoenike 1969; Van Haverbeke 1968b; Fassett 1944a).

In addition to the provenance studies cited previously, a number of current tree-improvement efforts are underway involving selection and testing of eastern redcedar. Davis⁸ in Georgia has propagated three strains of *J. virginiana* for improved Christmas trees that hold good winter foliage color and

⁸ T.S. Davis, Cultural practices and control of diseases of Christmas tree species in Georgia. U.S. Dep. Agric. Curr. Res. Inf. Ser. (CRIS). Ga. proj. terminated June 30, 1969.

have no prickly (acicular) foliage. McGinnis⁹ in Missouri evaluated wood quality and found a decreasing trend of specific gravity from pith to bark at breast height—a departure from other coniferous woods. Meahl¹⁰ in Pennsylvania studied the influence of parent materials and the use of growth regulators, temperatures, anti-transpirants, and photoperiods in relation to quantity and quality of rooting. Herman¹¹ in South Dakota has selected superior clones of *J. scopulorum*—a closely related taxon and very probably containing some *J. virginiana* germ plasm—showing a broad range of growth forms and foliage colors.

Most recent work in juniper improvement was initiated in late 1973 by the Technical Committee of the Great Plains Agricultural Council (GP-13). In an effort to find and identify better adapted juniper materials for use in the Great Plains, a regional plan (Van Haverbeke and Read 1974) was developed by State and Federal Cooperators, for sampling natural stands of *J. virginiana* and *J. scopulorum* in the 10 Plains States. Seed is being collected from five trees of most promising phenotypes in each of 60 seed zones (Cunningham 1975), and provenance tests of these sources are to be established in all Plains States beginning about 1977.

Plus-Tree Selection

Specific selection criteria will be tailored to meet the needs of the end product. Dawson and Read (1964), for example, listed superior height growth, straight stem, uniform medium crown density, and medium-broad crown as important selection criteria for eastern redcedar to be used as shelterbelt trees. Where eastern redcedar is to be grown for dimension lumber, selection might be based on rapid height and diameter growth, small self-pruning branches, narrow crown, and other commercially desirable characteristics. Where an improved Christmas tree is desired, selection emphasis would be placed on winter foliage color, foliage density, form, symmetry and balance of crown, branch and needle retention, and disease and insect resistance (Polk 1964).

The usual practice is to make individual selections from stands within the geographic region where the seed is to be planted (Limstrom 1965). Aside from convenience, this permits utilization of the best lo-

cally adapted germ plasm and tends to maximize compatibility among clones. If a seed source other than the local source is desired, however, trees could be selected from sites whose tree population carries a hybrid index or other computed values within the range of those determined for the local source (Van Haverbeke 1968b).

There are no known heritability data available for eastern redcedar to provide estimates of expected genetic gain from selection.

Seed Orchards

The production of genetically improved eastern redcedar presents some unique problems in selection and breeding. There is no record of seed orchard establishment for the species. While eastern redcedar can be propagated from cuttings with some measure of success, clonal propagation by grafting is the common horticultural practice. Although the per-cutting or per-graft cost may be too high at present for large forest plantings, the development of clonally propagated seed orchards may provide administrators of planting programs with a more reliable source of better seed than is now available in the widely scattered natural stands and older plantations.

Since the species is dioecious, both staminate and ovulate trees must be included in any seed orchard layout. This would tend to reduce the seed-producing efficiency per tree in the orchard unless the pollen donors were kept to a minimum. No data are available as to the ratio of staminate to ovulate trees in natural stands, but an assumption of 1:1 ± 10 percent would seem reasonable. It is the personal opinion of some that natural stands contain about 60–65 percent staminate trees—an approximate ratio of 3 to 2.

For seed orchard purposes, a ratio of 1 to 5 staminate to ovulate trees appears reasonable. A modified randomized complete block design, with ovulate selections randomized and the staminate selections equally spaced throughout, would probably provide for uniform distribution of pollen over the seed orchard.

Technical difficulties associated with breeding the extremely small ovulate strobili containing small numbers of seed may make full-sib progeny testing of seed orchard selections difficult. However, see Fechner (1975). Such devices as full-tree isolation chambers (plastic tents, large pollen discharge chambers) should be tried to solve this problem. Half-sib progeny tests of clonal selections, which would be much more convenient and less costly, may be entirely satisfactory in lieu of full-sib progeny tests.

Limstrom (1965) suggested seedling seed orchards as being more feasible than clonal orchards

⁹ E.A. McGinnis. Growth quality evaluation of the wood of oak, pine, and redcedar, U.S. Dep. Agric., Curr. Res. Inf. Ser. (CRIS). Mo. proj. terminated June 30, 1970.

¹⁰ R.P. Meahl, Asexual propagation of horticultural crops. U.S. Dep. Agric., Curr. Res. Inf. Ser. (CRIS). Pa. proj. terminated June 30, 1967.

¹¹ D.E. Herman, Selection and propagation of woody plants for the Northern Plains. U.S. Dep. Agric., Curr. Res. Inf. Serv. (CRIS). SD proj. terminated June 30, 1973.

for eastern redcedar. Until a technique for determining the sex of individual trees is developed, however, the apparent inability to distinguish between staminate and ovulate trees during the seedling stage may preclude the establishment of seedling orchards.

As an alternative to a clonal seed orchard, selected trees in natural stands could be inexpensively evaluated by means of half-sib progeny tests,

and production seed could be collected from the proven trees. This might be a feasible approach for genetically improved seed, since large quantities of seed are commonly produced on a given tree. This "less-intensive" tree improvement technique would be especially desirable if sufficient selected and progeny-tested trees grew conveniently close to one another.

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