Pinus aristata

- INTRODUCTORY
- DISTRIBUTION AND OCCURRENCE
- BOTANICAL AND ECOLOGICAL CHARACTERISTICS
- FIRE ECOLOGY
- FIRE EFFECTS
- MANAGEMENT CONSIDERATIONS
- REFERENCES

INTRODUCTORY

- AUTHORSHIP AND CITATION
- FEIS ABBREVIATION
- SYNONYMS
- NRCS PLANT CODE
- COMMON NAMES
- TAXONOMY
- LIFE FORM
- FEDERAL LEGAL STATUS
- OTHER STATUS

Nearly pure stand of bristlecone pine on the Pike National Forest, CO.
Photo by Dave Powell, USFS, www.forestryimages.org.

AUTHORSHIP AND CITATION:
Fryer, Janet L. 2004. Pinus aristata. In: Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: www.fs.fed.us/database/feis [2010, June 21].

FEIS ABBREVIATION:
PINARI

SYNONYMS:
None

NRCS PLANT CODE [147]:
PIAR

COMMON NAMES:
Rocky Mountain bristlecone pine
Colorado bristlecone pine

TAXONOMY:
The scientific name of Rocky Mountain bristlecone pine is *Pinus aristata* Engelm. (Pinaceae) [8,46,67,69,92,149].

Rocky Mountain bristlecone pine, Great Basin bristlecone pine (*P. longaeva*), and foxtail pine (*P. balfouriana*) share a common

ancestor [117,152]. Taxa within the bristlecone-foxtail pine complex (*Pinus*, subgenus *Strobus*, section *Parrya* Mayr, subsection *Balfourianae* Englm.) are distinguished by growth form, bark, and differences in chemical composition [8,32,93,100]. Bristlecone and foxtail pines readily produce fertile hybrids in the laboratory [131,152]. Disjunct distributions, and possibly other factors, prevent natural hybridization among the 3 species.

LIFE FORM:
Tree

FEDERAL LEGAL STATUS:
No special status

OTHER STATUS:
The World Conservation Union's Species Survival Commission (IUCB-SSC) lists Rocky Mountain bristlecone pine as a lower risk, near-threatened species: close to qualifying for "Vulnerable" status, with this classification needing updating [66]. Rocky Mountain bristlecone pine is protected from salvage in Arizona [4].

DISTRIBUTION AND OCCURRENCE

SPECIES: Pinus aristata

- GENERAL DISTRIBUTION
- ECOSYSTEMS
- STATES/PROVINCES
- BLM PHYSIOGRAPHIC REGIONS
- KUCHLER PLANT ASSOCIATIONS
- SAF COVER TYPES
- SRM (RANGELAND) COVER TYPES
- HABITAT TYPES AND PLANT COMMUNITIES

GENERAL DISTRIBUTION:
Rocky Mountain bristlecone pine occurs in the southern Rocky Mountains of Colorado, New Mexico, and Arizona. Its northernmost occurrence is in Gilpin County, Colorado, on the Front Range just south of Rocky Mountain National Park. Distribution continues south through the San Juan and Sangre de Cristo mountains to Mineral County, Colorado, and northern Santa Fe and San Miguel counties, New Mexico [11,90]. An outlier population occurs in Coconino County, northern Arizona, on the San Francisco Peaks [69,90].

The ranges of Great Basin and Rocky Mountain bristlecone pines do not overlap. The Colorado-Green River drainage has separated the 2 bristlecone pine species for millennia, and there is a 160-mile (260-km) gap between the 2 bristlecone species at their closest point in Utah and Colorado [57,101]. The U.S. Geological Survey provides distributional maps of Rocky Mountain bristlecone and Great Basin bristlecone pines.

ECOSYSTEMS [47]:
FRES20 Douglas-fir
FRES23 Fir-spruce
FRES26 Lodgepole pine

STATES/PROVINCES: (key to state/province abbreviations)
UNITED STATES
AZ CO NM

BLM PHYSIOGRAPHIC REGIONS [15]:
11 Southern Rocky Mountains
12 Colorado Plateau

KUCHLER [76] PLANT ASSOCIATIONS:

K008 Lodgepole pine-subalpine forest
K018 Pine-Douglas-fir forest
K021 Southwestern spruce-fir forest
K022 Great Basin pine forest

SAF COVER TYPES [41]:
206 Engelmann spruce-subalpine fir
209 Bristlecone pine
210 Interior Douglas-fir
218 Lodgepole pine
219 Limber pine

SRM (RANGELAND) COVER TYPES [127]:
None

HABITAT TYPES AND PLANT COMMUNITIES:
Rocky Mountain bristlecone pine occurs in upper montane and subalpine communities [149]. Engelmann spruce (*Picea engelmannii*) and limber pine (*Pinus flexilis*) associate with Rocky Mountain bristlecone pine throughout most of Rocky Mountain bristlecone pine's range. Rocky Mountain bristlecone pine tends to exclude Engelmann spruce and limber pine on upper subalpine and timberline sites. Even in lower subalpine sites, Rocky Mountain bristlecone pine is more common in mesic areas than limber pine [107]. Brunstein [23] noted limber pine was absent from Rocky Mountain bristlecone pine communities on the east slope of the Park Range of Colorado. Quaking aspen (*Populus tremuloides*) may co-occur throughout Rocky Mountain bristlecone pine's range on seral sites including burns. Rocky Mountain lodgepole pine (*Pinus contorta* var. *latifolia*) also occurs on new burns and other disturbed sites in Rocky Mountain bristlecone pine communities [73,107].

Rocky Mountain bristlecone pines often form monospecific krummholz woodlands at treeline. In mixed treeline stands, Rocky Mountain bristlecone pine may associate with common juniper (*Juniperus communis*), krummholz Engelmann spruce and more rarely, krummholz limber pine [21,107]. More detailed descriptions of plant composition in Rocky Mountain bristlecone pine communities are given below.

Colorado: Most Rocky Mountain bristlecone pine communities occur east of the Continental Divide in Colorado, although Rocky Mountain bristlecone pine forests occur on the west slope of the San Juan Mountains. Engelmann spruce, corkbark fir (*Abies lasiocarpa* var. *arizonica*), quaking aspen, and Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) are common associates. Subalpine fir (*A. l.* var. *lasiocarpa)* replaces corkbark fir in the northern limits of Rocky Mountain bristlecone pine's distribution [11].

Subalpine forests — Pure Rocky Mountain bristlecone pine and Rocky Mountain bristlecone pine-limber pine forests generally occur above Engelmann spruce-corkbark fir forests. Engelmann spruce is a nearly constant associate of Rocky Mountain bristlecone pine except near treeline, while corkbark fir is sparse to absent in some Rocky Mountain bristlecone pine communities [29]. Rocky Mountain bristlecone pine fingers into Engelmann spruce-corkbark (or subalpine) fir communities, usually occurring on xeric sites or at the highest elevations (~11,700 ft (3,580 m)) within the Engelmann spruce-fir types. It becomes less important with decreasing elevation [2,11,20,35,116].

Montane forests — On the Front Range, Rocky Mountain bristlecone pine, Rocky Mountain lodgepole pine, or quaking aspen may dominate upper montane forests. In structure and composition, montane Rocky Mountain bristlecone pine communities vary from dense forest to open conifer/grassland woodlands and savannas. The most common understory dominants in Rocky Mountain bristlecone pine/herbaceous types are Arizona fescue (*Festuca arizonica)*, Thurber fescue (*F. thurberi*), and alpine clover (*Trifolium dasyphyllum*) [33,59]. Tufted hairgrass (*Deschampsia cespitosa*), glaucous bluegrass (*Poa glauca*), bog sedge (*Kobresia myosuroides*), and other sedges (*Carex* spp.) are also common in the understory [11]. Ranne and others [110] identified 3 Rocky Mountain bristlecone pine/shrub types on the Front, Mosquito, and San Juan ranges. Common juniper, dwarf bilberry (*Vaccinium myrtillus*), or gooseberry currant (*Ribes montigenum*) were the understory dominants. Currants (*Ribes* spp.), dwarf bilberry, Oregon-grape (*Mahonia repens*), and common juniper often associate in the understory in Rocky Mountain bristlecone pine-Engelmann spruce forests [29]. Rocky Mountain bristlecone and limber pines are minor associates in Rocky Mountain lodgepole pine forests on the Gunnison National Forest [153].

New Mexico:
Subalpine forests — Rocky Mountain bristlecone pine communities occur near upper timberline. Engelmann spruce may be present in low numbers. A Rocky Mountain bristlecone pine/gooseberry currant series occurs between 10,500 and 11,800 feet

(3,200-3,600 m) elevation in the Sangre de Cristo Mountains [102]. The understory beneath high-elevation Rocky Mountain bristlecone pine communities may be sparse. Krebs [73] found composites (Asteraceae) and a few genera of grasses were present in a Rocky Mountain bristlecone pine community on the Rio Grande-Gunnison National Forest boundary. The understory was usually barren of other vegetation.

At lower subalpine and montane elevations, Rocky Mountain bristlecone pine-Thurber fescue savannas occur on deep soils. On shallower soils, Engelmann spruce-Rocky Mountain bristlecone pine and Rocky Mountain Douglas-fir-limber pine-Rocky Mountain bristlecone pine communities occur below the upper subalpine zone. These mixed-conifer types generally have more diverse understories than pure Rocky Mountain bristlecone pine forests. Associated understory species in Engelmann spruce-Rocky Mountain bristlecone pine communities include gooseberry currant, Wolf's currant (*R. wolfii*), and twinberry honeysuckle (*Lonicera involucrata*). Common graminoids are fringed brome (*Bromus ciliatus*), spike trisetum (*Trisetum spicatum*), glaucous bluegrass, nodding bluegrass (*P. reflexa*), and small-flowered woodrush (*Luzula parviflora*). Common forbs are alpine clover, single delight (*Moneses uniflora*), subalpine fleabane (*Erigeron peregrinus*), sickletop lousewort (*Pedicularis racemosa*), and Jacob's-ladder (*Polemonium pulcherrimum*) [102].

Rocky Mountain bristlecone pine also dominates lower subalpine zones [120]. Rocky Mountain Douglas-fir is a common component of low-elevation Rocky Mountain bristlecone pine habitat types [42]. In the Rocky Mountain bristlecone pine-Douglas-fir series, Rocky Mountain bristlecone pine retain codominance into old-growth stages. Grasses dominate the understory. Arizona fescue, fringed brome, mutton grass (*Poa fendleriana*), and slender wheatgrass (*Elymus trachycaulus*) are the principle grasses. Common forbs include alpine false springparsley (*Pseudocymopterus montanus*), pineywoods geranium (*Geranium caespitosum*), and bluebell blueflower (*Campanula rotundifolia*). A few shrubs may have scattered occurrence, particularly oceanspray (*Holodiscus dumosus*), currants, and snowberries (*Symphoricarpos* spp.) [102].

Montane forests — Rocky Mountain bristlecone pine dominates some lower subalpine and upper montane zones, particularly the conifer-grass associations. Low-elevation Rocky Mountain bristlecone pine savannas are structurally similar to interior ponderosa pine (*Pinus ponderosa* var. *scopulorum*) savannas [110]. Arizona fescue or Thurber fescue usually dominate the understory. In the Sangre de Cristo Mountains, montane Rocky Mountain bristlecone pine/Thurber fescue communities extend from upper montane to lower subalpine zones [49,102,110]. Commonly associated graminoids in Rocky Mountain bristlecone pine savannas include prairie Junegrass (*Koeleria macrantha*), mountain muhly (*Muhlenbergia montana*), dryspike sedge (*Carex foenea*), and loving sedge (*C. pityophila*). Forbs include alpine clover, starry Solomon's seal (*Maianthemum stellatum*), and western yarrow (*Achillea millefolium*). Common juniper, fringed sagebrush (*Artemisia frigida*), bearberry (*Arctostaphylos uva-ursi*), wax currant (*R. cereum*), gooseberry currant, and mountain snowberry (*Symphoricarpos oreophilus*) are common shrubs.

A Rocky Mountain Douglas-fir-limber pine-Rocky Mountain bristlecone pine montane forest series also occurs in the Sangre de Cristo Mountains. Blue spruce (*Picea pungens*) occurs in these mixed forests [102,135].

Arizona:
Subalpine forests — Rocky Mountain bristlecone pine forms a krummholz community with corkbark fir and Engelmann spruce on the San Francisco Peaks. It is usually dominant on upper subalpine sites, although Engelmann spruce may dominate the relatively coldest sites and sometimes grows above Rocky Mountain bristlecone pine. Limber pine also associates with Rocky Mountain bristlecone pine in upper subalpine zones [86,106,115]. Shrubs and herbs are sparse in upper subalpine Rocky Mountain bristlecone pine communities. Common juniper and gooseberry currant are the most frequent shrubs; common herbs include dark beardtongue (*Penstemon whippleanus*), golden draba (*Draba aurea*), alpine pennycress (*Thlaspi montanum* var. *fendleri*), and alpine fescue (*F. brachyphylla*) [115]. Rocky Mountain bristlecone pine communities merge with mixed Engelmann spruce-corkbark fir forest at lower subalpine zones and with alpine meadows, cushion plant communities, and bare rock above about 11,000 feet (3,500 m) elevation [106].

Mixed-montane forests where Rocky Mountain bristlecone pine forms an important component of the overstory are poorly described for Arizona. White fir (*Abies concolor*), blue spruce, and quaking aspen may associate with Rocky Mountain bristlecone pine on mixed-conifer sites [124]. Descriptions of characteristic understory species for Rocky Mountain bristlecone pine-mixed montane forest types are lacking as of this writing (2004).

Vegetation classifications describing Rocky Mountain bristlecone pine communities include:

Arizona [85,86,115]
Colorado [33,59,71,72,110]
New Mexico [33,34,85,86,102,110,135]

BOTANICAL AND ECOLOGICAL CHARACTERISTICS

SPECIES: Pinus aristata

- GENERAL BOTANICAL CHARACTERISTICS
- RAUNKIAER LIFE FORM
- REGENERATION PROCESSES
- SITE CHARACTERISTICS
- SUCCESSIONAL STATUS
- SEASONAL DEVELOPMENT

Photo by Dave Powell, USFS, www.forestryimages.org.

GENERAL BOTANICAL CHARACTERISTICS:
The following description of Rocky Mountain bristlecone pine provides characteristics that may be relevant to fire ecology, and is not meant for identification. Identification keys are available [8,46,67,69,92,149].

Morphology: Rocky Mountain bristlecone pine is a native conifer. Growth habit is varied and mostly dependent upon elevation. Rocky Mountain bristlecone pine forms krummholz at treeline, and grows as a small tree at upper subalpine elevations. On favorable low-elevation sites it often reaches 40 feet (12 m) in height and 30 inches (75 cm) in circumference [46,69,92]. The 2 champion trees are in New Mexico. They are 72 feet (22 m) tall and 11.5 feet (3.5 m) in diameter, and 76 feet (23 m) tall and 11 feet (3.4 m) in diameter, respectively [3]. The type specimen is from Pike's Peak, Colorado.

Trunks are usually single, but some Rocky Mountain bristlecone pines have multiple trunks [73]. Bark of Rocky Mountain bristlecone pine is thin, about 0.2 to 0.75 inch (0.5-1.9 cm) thick at maturity [31,96]. Branches of younger trees are low and ascending, forming a densely spreading, conical crown. Old trees form an irregular crown with upper limbs ascending and lower limbs deflexed [46,69,92]. Old trees show vertical strips of dead ribbonwood, many dead branches, and crown die-back [73,119].

The *Balfourianae* complex is unique among pines in that about half of their branches originate from within the needle fascicles [28,62]. Needles are 1 to 2 inches (2.5-5 cm) long, with 5 to a fascicle. They tend to be crowded and thick towards the ends of the branches [46,69,92]. Needles are usually retained for 10 to 15 years; rarely, they may stay on the tree for 20 or more years [8,40]. The needles and cones are sticky and resinous [8,101]. Pollen cones are about 0.4 inch (10 mm) long; female cones are 2 to 4.3 inches (6-11 cm) long. Cone scales are armed with a small bristle. Seeds are 5 to 6 mm long; the seed wing is 10 to18 mm long [46,69,92,95]. Seed weight averages 50 mg [95].

Root architecture of Rocky Mountain bristlecone pine is not described in the literature (as of 2004). Oswald and Ferchau [105] provide a list of some of Rocky Mountain bristlecone pine's associated mycorrhizae.

Age class structure: Rocky Mountain bristlecone pine stands are generally mixed-aged; however, old-growth stands may contain few or no young Rocky Mountain bristlecone pines [25].

Rocky Mountain bristlecone pines are long lived. They do not attain the extreme old ages that some Great Basin bristlecone pines do, but some Rocky Mountain bristlecone pines reach 1 or 2 millennia in age. The oldest Rocky Mountain bristlecone pines occur on high-elevation, dry sites that promote slow rates of tree growth and heart rot decay [25,73,74]. A dozen Rocky Mountain bristlecone pines in the South Park area of Colorado are documented as over 1,600 years of age. The oldest known Rocky Mountain bristlecone pine grows in the southern Front Range. It had 2,435 countable annual rings in 1992; its actual age was estimated at 2,500 years [22,25]. The oldest known Rocky Mountain bristlecone pines in Arizona are on the San Francisco Peaks near Flagstaff. One Rocky Mountain bristlecone pine in the area was documented at 1,438 years of age in 1984 [137].

Rocky Mountain bristlecone pines in lower subalpine habitats are more susceptible to heart-rot fungi and other mortality agents than trees at high elevations. Rocky Mountain bristlecone pines in montane Rocky Mountain bristlecone pine/Thurber fescue

habitats, for example, do not live much over 300 years [34].

Stand structure of Rocky Mountain bristlecone pine communities is varied. Rocky Mountain bristlecone pine/alpine clover habitat types on the Arapaho National Forest of Colorado have a moderately closed canopy [59]. The Sawatch and Front ranges support moderate to dense, nearly pure Rocky Mountain bristlecone pine forests on lower subalpine, dry sites [22]. Engelmann spruce, subalpine fir, Rocky Mountain lodgepole pine, and/or limber pine are also present on mesic sites, and mixed stands are generally less dense than pure Rocky Mountain bristlecone pine stands. At other locations in the southern Rocky Mountains, Rocky Mountain bristlecone pine occurs in pure or mostly pure, open groves of varied extent. Some groves are large enough to cover entire upper subalpine watersheds; others are small and isolated. On some sites, tree-sized Rocky Mountain bristlecone pine may overtop krummholz Engelmann spruce and corkbark (or subalpine) fir, which are less tolerant of desiccation [61].

Baker [11] measured density of Rocky Mountain bristlecone pines in various stages of postfire succession in Colorado. In early seres, mean density of Rocky Mountain bristlecone pine seedlings was 350/ha. Sapling density averaged 13/ha. There were a few pole-sized trees ranged from 2 to 5.9 inches (5-15 cm) in diameter. As stand age increased, size classes attained a normal distribution. Most Rocky Mountain bristlecone pines were in the 9.8- to 18-inch (25- to 45-cm) diameter classes, but ranged from seedling to 28-inch (70-cm) diameter classes.

In Pike National Forest, Colorado, some montane Rocky Mountain bristlecone pine communities structurally resemble open ponderosa pine savannas, with widely spaced trees and grassy understories [35].

RAUNKIAER [111] LIFE FORM:
Phanerophyte

REGENERATION PROCESSES:
Rocky Mountain bristlecone pine reproduces from seed [51,75,82,123]. Regeneration requirements for successful bristlecone pine establishment are rarely met [17,70], but as an extremely long-lived species, Rocky Mountain bristlecone pine has centuries to millennia to wait for favorable regeneration conditions.

Studies on bristlecone pine regeneration have primarily focused upon Great Basin bristlecone pine. Similar studies are needed on Rocky Mountain bristlecone pine regeneration, especially in the areas of seed biology, the relative role of Clark's nutcracker in successful Rocky Mountain bristlecone pine establishment, and genetics.

Breeding system: Rocky Mountain bristlecone pine is monoecious [83].

Pollination: Bristlecone pines are pollinated by wind [83]. Mating system is predominantly outcrossing [60,88].

Seed production: Minimum observed age of seed production in Rocky Mountain bristlecone pine is 10 to 40 years [51,75,82,123]. Cone crop production is generally steady, with heavy cone crops every few years. Rodents may consume large numbers of seeds [51].

Seed dispersal: Seeds disperse by wind [81,96]. Clark's nutcrackers also disperse some Rocky Mountain bristlecone pine seeds [148], although they prefer the larger seeds of limber pine and pinyon pines (Cembra). Clark's nutcrackers are most likely to cache Rocky Mountain bristlecone pine seeds when seed crops of preferred species are poor [148]. Seed dispersal by Clark's nutcrackers has important implications for Great bristlecone pine's genetic structure and ability to establish on disturbed sites such as burns. Clark's nutcrackers bury seeds in caches. A growth form of clumped trees that fuse at the stem is characteristic of establishment resulting from Clark's nutcracker seed dispersal [80]. When an individual tree has multiple stems, genetic marker tests show each stem is genetically identical. If several individual trees fuse at the base as a result of close planting by Clark's nutcrackers, forming a multi-stemmed tree clump, individual stems retain their separate genetic identities. Genetic marker tests can show if fused stems are genetically identical or different [139]. Torick and others [141] used electrophoresis to determine the genetic composition of multistemmed Rocky Mountain bristlecone pine clusters on Goliath Peak, Arapaho National Forest, Colorado. They found that 20% of clumps were multigenetic.

Seed banking ability of Rocky Mountain bristlecone pine is unknown. Laboratory seed germination tests suggest Rocky Mountain bristlecone pine may not build a long-term seed bank [38,114], yet seed caching by Clark's nutcrackers suggests the possibility of a seed bank. Further studies are needed in this area.

Germination: Most Rocky Mountain bristlecone pine seeds require no stratification period and are immediately germinable when ripe [38,84,114]. A stratification period of up to 30 days may improve germination of some seeds [38]. Seeds from a collection on Pike's Peak near the headwaters of Clear Creek, Colorado (the type location), showed 80% germination. Stratification

did not improve germination rates [114].

Seedling establishment is generally rare. Rocky Mountain bristlecone pine seedlings usually establish 600 feet (200 m) or more from parent trees. Best germination and establishment occurs on open, bare mineral soil [51]. In Colorado, Baker [11] found best Rocky Mountain bristlecone pine regeneration occurred on sites that had burned within the last few decades. Rocky Mountain bristlecone pine failed to regenerate under closed canopies. Seedlings can also establish in small openings. Schubert and Rietveld [124] noted a young, pure stand of Rocky Mountain bristlecone pine on the San Francisco Peaks that established in a clearing within mixed-conifer montane forest.

Growth is affected by the previous year's climate. In the Bristlecone Pine Scenic Area, Colorado, high monsoonal precipitation in July, August, and September of the previous year was positively associated ($p<0.05$) with early summer growth. La Nina events tended to reduce growth. La Nina 's high fall temperatures reduced growth the next year, probably because buds failed to harden off and were frost-killed [35].

Rocky Mountain bristlecone pine is slow growing. Trees from 16 to 20 inches (41-51 cm) in diameter have been aged at 200 to 250 years [51]. A study on the Mt. Goliath Research Natural Area, Colorado, showed Rocky Mountain bristlecone pine attained less annual stem growth, but retained more needle biomass per shoot, compared to associated Rocky Mountain lodgepole pine. Mean shoot growth on small-diameter (<3 in. (7 cm)) Rocky Mountain bristlecone pines was 0.75 inch (1.9 cm) per year, while large-diameter (>20 in. (50 cm)) Rocky Mountain bristlecone pine shoots gained an average of 0.6 inch (1.5 cm) per year [122].

SITE CHARACTERISTICS:
Rocky Mountain bristlecone pine is most common on dry slopes. Slopes are typically steep (20-35°), and aspects are usually south- or west-facing, although Rocky Mountain bristlecone pine may occur on any aspect with well-drained soil [11,43]. Where limber and Rocky Mountain bristlecone pines co-occur, limber pine may dominate the rockier, drier ridges [31].

Climate: Climate is continental and cold on Rocky Mountain bristlecone pine sites. Mean annual temperature in Rocky Mountain bristlecone pine forests of New Mexico is 35 °F (1.5 °C), and the growing season is less than 110 days [102]. Rocky Mountain bristlecone pine groves are interspersed with permanent snowfields on upper subalpine sites in the southern Front Range [23,24]. Mean annual precipitation is 34 to 45 inches/year (860-1,100 mm/year) [101,102].

Precipitation patterns are influenced by summer monsoons, which bring regular afternoon thundershowers and lightning. Precipitation increases from its minimum during December and January to its maximum in July and August. New Mexico receives the most monsoonal rainfall within Rocky Mountain bristlecone pine's distribution, while northern Colorado receives the least monsoonal rainfall [12,35]. El Niño-La Niña events bring heavy snowfalls during El Niños and drought during La Niñas [12].

Annual precipitation received varies greatly on Rocky Mountain bristlecone pine sites in the central Rocky Mountains. For example, Rocky Mountain bristlecone pine stands near Pike's Peak on the Front Range receive as little as 16 inches (410 mm) of annual precipitation, while stands further west in the Sawatch and San Juan ranges receive 40.2 and 59.8 inches (1,020 and 1,520 mm) of mean annual precipitation, respectively [25,73].

Soils supporting Rocky Mountain bristlecone pine are cold, and generally nutrient-poor and acidic. They are classified near the extreme end of cryllic, with mean temperatures around 33 °F (1 °C) [102]. Soils are typically skeletal and shallow, ranging from 2 to 4 inches (5-10 cm) deep [11]. Some montane Rocky Mountain bristlecone pine communities adjoining mountain meadows occur on deep soils [102].

Unlike Great Basin bristlecone pine, which is largely restricted to basic soils, soils supporting Rocky Mountain bristlecone pine range from less than 5.1 to 7.7 in pH [101,110]. Rocky Mountain bristlecone pine is common on granitic soils, which are usually acidic. Parent materials for Rocky Mountain bristlecone pine soils vary. In Colorado, granite and extrusive igneous-derived soils are most common; gneiss- and schist-derived soils are least common [11,24]. In New Mexico, Rocky Mountain bristlecone pine grows on loamy cherts [101].

Nutrients — Nitrogen is usually limiting on Rocky Mountain bristlecone pine soils [150]. On Goliath Peak, Colorado, soils beneath Rocky Mountain bristlecone pines were low in nitrogen and phosphorus, while soils supporting Engelmann spruce were also low in nitrogen but higher in phosphorus than Rocky Mountain bristlecone pine soils. The authors suggested that Rocky Mountain bristlecone pines may be long-term phosphorus sinks [126].

Because of atmospheric deposition of nitrogen on high-elevation sites, phosphorus may be replacing nitrogen as the limiting nutrient on upper subalpine and treeline Rocky Mountain bristlecone pine communities on the Front Range. In 1 study, phosphorus was limiting on high-elevation study sites in the Front Range. Nitrogen was still the limiting nutrient on lower-elevation study sites

in the Front Range, and on all subalpine and montane study sites in New Mexico and Arizona [150].

Elevation: Rocky Mountain bristlecone pine generally occurs from 8,200 to 11,000 feet (2,500-3,400 m) [46]. Elevational range by state is:

State	
Arizona	9,500-12,000 feet (2,900-3,700 m) [69]
Colorado	7,000-13,000 feet (2,100-4,000 m) [54,73]
New Mexico	10,000-12,000 feet (3,000-3,700 m) [92]

Rocky Mountain bristlecone pine distribution migrates upslope in response to climate warming. A dendrochronological study on Mt Evans, Colorado, showed Rocky Mountain bristlecone pines grew as much as 130 feet (40 m) above present treeline from 1800 to 1500 BP [151].

SUCCESSIONAL STATUS:
Rocky Mountain bristlecone pine occurs in early seral and old-growth stages [134]. It usually dominates both new and old-growth forests and woodlands at high elevations [31]. It is a seral species in upper montane Engelmann spruce-corkbark (or subalpine) fir forests [1,31,113]. At its lowest elevational limits, Rocky Mountain bristlecone pine may be a seral or minor species in Rocky Mountain Douglas-fir forests [31]; however, Rocky Mountain bristlecone pine remains codominant on some Rocky Mountain Douglas-fir-limber pine-Rocky Mountain bristlecone pine communities into late succession [102].

Fire may be the primary disturbance in Rocky Mountain bristlecone pine-dominated forests. In a study across Rocky Mountain bristlecone pine's range in Colorado, Baker [11] found most Rocky Mountain bristlecone pine regeneration occurred after stand-replacing fire.

Succession is slow on cold sites dominated by Rocky Mountain bristlecone pine [26,102]. Baker [11] found that in Colorado, postfire Rocky Mountain bristlecone pine establishment was uneven-aged, with some trees establishing decades after the last fire. Even so, Rocky Mountain bristlecone pine was the most commonly occurring tree in postfire succession in upper subalpine forests. Limber pine also established relatively soon after fire, but was not as dense as Rocky Mountain bristlecone pine. Engelmann spruce established in low numbers in early postfire succession, but was more common in late seres. Quaking aspen co-occurred in some seral Rocky Mountain bristlecone pine stands that ranged from 89 to 550 years of age [11].

With long fire-free intervals, mountain meadow communities may succeed to mixed forests of Rocky Mountain bristlecone pine and other conifers, especially when fire exclusion is accompanied by heavy livestock or pocket gopher grazing [102]. Baker [11] suggested that in the long-term absence of fire (>1,000 years), Rocky Mountain bristlecone pine may be replaced by Engelmann spruce or corkbark fir. He further stated that it is unlikely that fire could be excluded for so long, so "the chance of replacement by other species is small."

Rocky Mountain bristlecone pine is shade intolerant [9,31,112] and does not regenerate under its own canopy [11]. Both dry site conditions and cattle grazing may favor Rocky Mountain bristlecone pine over Engelmann spruce (see Discussion and Qualification of Plant Response) [10]. Rocky Mountain bristlecone pine's successional relationship with quaking aspen is unclear, since both species are shade intolerant. Rocky Mountain bristlecone pine, quaking aspen, Rocky Mountain Douglas-fir, interior ponderosa pine, and Rocky Mountain lodgepole pine may all be seral in Engelmann spruce-corkbark (or subalpine) fir communities [31].

SEASONAL DEVELOPMENT:
Time of Rocky Mountain bristlecone pine pollination ranges from late June to late July [37]. Female cones mature in autumn of their 2nd year. Rocky Mountain bristlecone pine cones drop soon after the seed has matured and shed [46]. On the San Francisco Peaks, Rocky Mountain bristlecone pines begin vegetative growth in early June. Buds burst and shoots elongate in mid-June. New cones open for pollination in late July. Pollen disperses for about 5 days, extending pollination to early August. Second-year female cones 1st open for seed dispersal in late September, when active growth stops. Most seeds disperse in early October. Needles abscise through October [73,124].

FIRE ECOLOGY

SPECIES: Pinus aristata

- FIRE ECOLOGY OR ADAPTATIONS
- POSTFIRE REGENERATION STRATEGY

FIRE ECOLOGY OR ADAPTATIONS:

Fire adaptations: Rocky Mountain bristlecone pine can survive low-severity surface fire [73]. It has thin bark and a low branching habit [31], so it is poorly adapted to survive more severe fire.

As a shade-intolerant, seral species, Rocky Mountain bristlecone pine is favored in early postfire succession [11,123]. Fire may be the primary disturbance in montane and lower subalpine Rocky Mountain bristlecone pine forests. In a study across Rocky Mountain bristlecone pine's range in Colorado, Baker [11] found most Rocky Mountain bristlecone pine establishment occurred 20 to 75 years after stand-replacing fire. Fire creates a favorable seedbed of bare mineral soil, and Rocky Mountain bristlecone pine establishes on burns from wind-blown seed [23,81,113]. Since some Rocky Mountain bristlecone pine seed is dispersed by Clark's nutcrackers [80,148], establishment from Clark's nutcracker seed caches is also possible.

Fuels: Few descriptions of fuels loads in Rocky Mountain bristlecone pine communities are available. One study showed that across the species' range in Colorado, Rocky Mountain bristlecone pine communities typically had litter layers less than 0.8 inch (2 cm) thick. Area beneath most stands was 25% or less bare rock, although 100% rock cover occurred beneath a few stands [11]. Because of open structure and sparse fuels, fires seldom crown in Rocky Mountain bristlecone pine/fescue types [33]. Denser Rocky Mountain bristlecone pine communities probably have heavier fuel loads, and more studies are needed to better describe fuel loadings in various Rocky Mountain bristlecone pine types.

Fire regimes: Rocky Mountain bristlecone pine was historically subject to the full range of fire regimes: understory surface fires, mixed-severity fires, and stand-replacement, severe surface and crown fires [49,102,120,134]. Fire does not appear to be a major disturbance factor in **treeline and upper subalpine** Rocky Mountain bristlecone pine communities. Lightning-ignited fires are common, but they are usually of low severity and small extent because patchy stand structure and low fuel loadings limit fire spread [31]. Biomass production is limited by the short, cool growing seasons and poorly developed soils [70], so there is generally not enough fuel to carry fire [31,70]. Fire is infrequent and has unpredictably long fire return intervals on high-elevation bristlecone pine sites [70].

Pure Rocky Mountain bristlecone pine subalpine forests historically experienced long interval (300+ years), stand-replacement fires and more frequent, low-severity surface fires [102,134]. On 8 sites on Colorado's Front Range, fire return intervals in subalpine Engelmann spruce-Rocky Mountain bristlecone pine forests ranged from 200-600 years [113]. In a study across Rocky Mountain bristlecone pine's range in Colorado, Baker [11] similarly found a fire return interval of 200-500+ years in Rocky Mountain bristlecone pine subalpine forests. Both fire occurrence and Rocky Mountain bristlecone pine establishment were common between 1625-1700, a period of above-average temperatures. Fires were also widespread in Colorado in the exceptionally dry summer of 1900. Heavy postfire Rocky Mountain bristlecone pine seedling establishment occurred from 1900-1925.

Engelmann spruce-corkbark fir forests of the middle and southern Rocky Mountains, where Rocky Mountain bristlecone pine is seral, are subject to long fire-return interval, stand-replacement fires and mix-severity fires in **middle subalpine zones**. Fire regimes where Rocky Mountain bristlecone pine predominates at those elevations are difficult to determine. Bristlecone pines often do not show fire-scar injuries typical of other pines (Harlin [53], personal communication), [125]. Instead of growing new cambial tissue over fire-killed tissue, bristlecone pines more typically form horizontal ribbonwood scars (Harlin [53], personal communication). A common response to wind and weather damage at timberline, where fires are rare, ribbonwood scarring may also be a common response to fire injury by Rocky Mountain bristlecone pines in lower subalpine forests. Because of the difficulty in finding chronological fire scars in Rocky Mountain bristlecone pine, fire histories of subalpine forests are often documented using fire-scarred Engelmann spruce and limber pine. Although valuable, such studies do not directly document fire history in stands dominated by Rocky Mountain bristlecone pine. In structure, Rocky Mountain bristlecone pine-dominated stands tend to be more open, and patchy in extent, than surrounding Engelmann spruce-dominated forest; therefore, fire return intervals in Rocky Mountain bristlecone pine-dominated stands may differ from the adjacent subalpine forest. For example, a study on the Mt. Evans Wilderness, Colorado, Rocky Mountain bristlecone pine stands tended to have shorter fire return intervals compared to the surrounding forest. Mean fire return interval was 13.1 years, ranging from 3 to 50 years. In contrast, mean fire return interval on nearby Engelmann spruce-dominated forest in the Arapaho National Forest was 16.4 years, ranging from 1 to 73 years [125].

Low-severity surface fires predominate on **lower subalpine** sites where Rocky Mountain bristlecone pine occurs in open, pure stands or with Engelmann spruce. In a study on Pike National Forest, central Colorado, fire return intervals in Rocky Mountain bristlecone pine-Engelmann spruce forests ranged from 9 to 55 years. Stand structure was similar to open, lower-elevation interior ponderosa pine forest [35,36].

In **mixed-conifer montane forests** with a Rocky Mountain bristlecone pine component, fires may be surface, mixed-severity, or long-interval, stand-replacement. Stand-replacement fires are most common during drought, and usually spread from lower-elevation interior ponderosa pine or pinyon-juniper (*Pinus-Juniperus* spp.) forests [45]. Rocky Mountain Douglas-fir-limber pine-Rocky Mountain bristlecone pine montane forests historically experienced frequent return-interval surface and mixed-severity fires [49,102]. Some old-growth trees in the Rocky Mountain Douglas-fir-limber pine-Rocky Mountain bristlecone pine bear old fire scars, evidence of past low-severity fire [34]. On very harsh sites in the montane zone, Rocky Mountain bristlecone pine may form self-replacing stands that accumulate litter more slowly than more mesic montane sites [103,107,113]. Such sites burn infrequently, allowing enough time for Rocky Mountain bristlecone pines to develop insulating bark that provides protection from low-severity surface fires.

The following table provides fire return intervals for plant communities and ecosystems where Rocky Mountain bristlecone pine is important. For further information, see the FEIS summary on the dominant species listed below.

Community or Ecosystem	Dominant Species	Fire Return Interval Range (years)
Engelmann spruce-subalpine fir	*Picea engelmannii-Abies lasiocarpa*	35 to > 200 [5]
Rocky Mountain bristlecone pine	*Pinus aristata*	9-55 [35,36]
Rocky Mountain lodgepole pine*	*P. contorta* var. *latifolia*	25-340 [13,14,138]
Rocky Mountain Douglas-fir*	*Pseudotsuga menziesii* var. *glauca*	25-100 [5,6,7]

*fire return interval varies widely; trends in variation are noted in the species review

Climatic influences: El Niño-La Niña cycles greatly influence fire frequency and severity, especially in the southern Rocky Mountains. Low snowpacks during La Niñas increase the likelihood of summer fires ([12], and references therein). Both alone and synergistically, El Niño-La Niña cycles and human management practices have increased fire activity in many Rocky Mountain bristlecone pine communities. A study on Pike National Forest showed the long-term relationship between El Niño-La Niña events and fire frequency and severity. Fires in Rocky Mountain bristlecone pine-Engelmann spruce communities were often preceded by 2 to 4 years of increased moisture availability (El Niño years). Trees showed increased growth during El Niño events; presumably, fuels increased as a result of increased herbaceous and woody plant growth. Fires were associated with reduced moisture availability in subsequent La Niña years. Fire occurrence from 1550-1792 was "moderate." Coincident with the "Little Ice Age," there were few fires from 1792-1842. Fire activity was high from 1850 until 1920. Several years (1748, 1851, and 1871) were marked by widespread fires that burned entire landscapes. The period of high fire activity occurred during both a long-term drought and a sharp increase in European-American settlement in the area. The number of fires declined sharply in 1920, when effective fire exclusion began [35,36].

Some Rocky Mountain bristlecone pine communities may still be functioning within historic fire regime parameters. In a study in the Mt. Evans Wilderness, Sherriff and others [125] found fire return intervals in upper-subalpine Rocky Mountain bristlecone pine forests were within the historic range of variability. The authors determined that fire occurrence in upper subalpine Rocky Mountain bristlecone pine and Engelmann spruce forests was largely determined by climate. They stated that unlike lower-elevation forests, human management practices over the past 200 years had little influence over upper-subalpine fire regimes in Mt. Evans Wilderness. Fire cycles were largely tied to drought associated with La Niña events.

Other, less well-known climate cycles that may influence fire regimes in Rocky Mountain bristlecone pine communities include sunspots, long-term lunar effects on tides, and long-term ocean oscillations. Baker [11] found the age of several Rocky Mountain bristlecone pine stands in the southern Rocky Mountains coincided with a period of increased fire frequency during the Maunder sunspot minimum.

POSTFIRE REGENERATION STRATEGY [133]:
Tree without adventitious bud/root crown
Initial off-site colonizer (off-site, initial community)
Secondary colonizer (on-site or off-site seed sources)

FIRE EFFECTS

SPECIES: Pinus aristata

IMMEDIATE FIRE EFFECT ON PLANT
- DISCUSSION AND QUALIFICATION OF FIRE EFFECT
- PLANT RESPONSE TO FIRE
- DISCUSSION AND QUALIFICATION OF PLANT RESPONSE
- FIRE MANAGEMENT CONSIDERATIONS

IMMEDIATE FIRE EFFECT ON PLANT:
Low-severity surface fire may cause basal wounds and scorch or kill lower Rocky Mountain bristlecone pine branches [73]. More severe fires kill Rocky Mountain bristlecone pine [20,73]. On the east slope of the Sawatch and Front ranges, Brunstein [23] noted various fire effects on Rocky Mountain bristlecone pines. Some living Rocky Mountain bristlecone pines showed charred branches and basal fire scars on low-severity burns. All trees were dead on severe burns, leaving charred, "ghost forest" snags. Fire did not carry to Rocky Mountain bristlecone pine stands surrounded by rock, although lightning strikes within isolated stands caused small fires that damaged or killed some trees.

Mostly low-severity fires with patches of more severe fire are common in Rocky Mountain bristlecone pine stands, and fire survival is also mixed on such sites. In a study of 4 Rocky Mountain bristlecone pine stands in Colorado, some live trees from each stand showed fire scarring, and each stand contained a few dead trees that were either fire-girdled or had torched [73].

Surface fire kills Rocky Mountain bristlecone pine seeds exposed on the soil surface [51]. Seeds stored below ground in Clark's nutcracker caches are insulated from fire damage [140].

DISCUSSION AND QUALIFICATION OF FIRE EFFECT:
No additional information is available on this topic.

PLANT RESPONSE TO FIRE:
Rocky Mountain bristlecone pine establishes on young burns from wind-blown seed [23], and probably from Clark's nutcracker caches [80,148]. Because it is a shade-intolerant species, the mineral soil and open space on burns provide favorable sites for seedling establishment. Rocky Mountain bristlecone pine seedlings and saplings have been observed on young burns in the Front and Sawatch ranges [23].

Plant succession is slow in the cold, dry Rocky Mountain bristlecone pine subalpine habitats. Early postfire succession may last a century or more [16,20,26,31,130]. In New Mexico, soil temperatures at 20 inches (50 cm) below ground are around freezing on high-elevation Rocky Mountain bristlecone pine burns [26]. Establishment usually follows a simple successional trajectory, with Rocky Mountain bristlecone pine dominating all stages of postfire succession in upper subalpine zones [31]. It may take several centuries for stands to reach full postfire stocking [34]. Over time, local lightning fires may create a mosaic of different-aged stands [31].

DISCUSSION AND QUALIFICATION OF PLANT RESPONSE:
Grazing and aspect may affect postfire successional trajectories. Postfire grazing in Engelmann spruce communities can favor Rocky Mountain bristlecone pine. A stand-replacement fire occurred around 1867 in an Engelmann spruce-dominated watershed near Pike's Peak, Colorado. Range managers built a fence running down the middle of the burned watershed between 1980 and 1902, so cattle were excluded from half of the burn. Grazing was heavy until the mid-1930s; after that, grazing intensity was reduced to less than 20% of previous levels. A fire history study was conducted in 1990. Aspects on study plots were east and west; elevation was 11,055 feet (3,350 m). Few Rocky Mountain bristlecone pines were present on study plots prior to the fire. The prefire stand was dominated by Engelmann spruce that were 6 to 10 inches (15-25 cm) in diameter. Engelmann spruce establishment began at postfire year 1 and continued steadily until 1920. There was a pulse of Engelmann spruce establishment in 1940, when grazing intensity decreased on the fenced side of the burn [10].

Rocky Mountain bristlecone pine 1st established on the study plots in 1910. It showed another pulse of establishment in 1928, and another strong pulse from 1935 to the early 1950s. Rocky Mountain bristlecone pine establishment from 1935 to 1953 was significantly greater ($p=0.05$) on grazed plots compared to ungrazed plots, and was more common on dry, west-facing aspects compared to east-facing aspects. Baker [10] stated that after fire, Rocky Mountain bristlecone pine can become dominant on dry aspects with or without grazing, and that postfire grazing favors Rocky Mountain bristlecone pine over Engelmann spruce.

FIRE MANAGEMENT CONSIDERATIONS:
Fire is used as a management tool to promote whitebark pine (*Pinus albicaulis*), a related 5-needle white pine (*Strobus*), in blister rust-infected areas. Fire management strategies used on whitebark pine can be applied to Rocky Mountain bristlecone pine. Fire-created openings provide establishment sites for natural regeneration of early successional white pines including Rocky Mountain bristlecone pine. Most importantly, fire-created openings can provide opportunities for natural and artificial regeneration of genetically blister rust-resistant Rocky Mountain bristlecone pine. Protecting blister rust-resistant parent trees from fire, while

encouraging natural selection of blister rust-resistant seedlings by providing a suitable open, mineral soil seedbed, is the best hope for restoring Rocky Mountain bristlecone pine communities in the long term [121,123].

Incomplete understanding of the fire and basic ecology of Rocky Mountain bristlecone pine constrain ability to implement management and conservation programs for Rocky Mountain bristlecone pine [121]. Fire restoration research is needed in Rocky Mountain bristlecone pine communities.

MANAGEMENT CONSIDERATIONS

SPECIES: Pinus aristata

- IMPORTANCE TO LIVESTOCK AND WILDLIFE
- VALUE FOR REHABILITATION OF DISTURBED SITES
- OTHER USES
- OTHER MANAGEMENT CONSIDERATIONS

IMPORTANCE TO LIVESTOCK AND WILDLIFE:
Little is known regarding wildlife use of many Rocky Mountain bristlecone pine habitats. Rocky Mountain bristlecone pine/grassland communities provide important, nutritional forage for big game animals. Rocky Mountain bristlecone pine/Thurber fescue communities are important summer ranges for elk [33]. Red squirrels and Clark's nutcrackers eat and cache Rocky Mountain bristlecone pine seeds [44,80]. The seed probably provides valuable food for other animals as well. Further research is needed on wildlife use of Rocky Mountain bristlecone pine habitats.

Palatability/nutritional value: No information is available on this topic.

Cover value: No information is available on this topic.

VALUE FOR REHABILITATION OF DISTURBED SITES:
Rocky Mountain bristlecone pine tolerates some toxic conditions and has potential value in restoring old mine and other polluted sites. On abandoned surface mines in Colorado, Rocky Mountain bristlecone pine seedlings were planted on topsoil-treated and overburden sites. Two years after planting, Rocky Mountain bristlecone pines showed 8.4 inches (21 cm) and 5.6 inches (14 cm) of height growth on topsoil and overburden sites, respectively. Survival was 100% on both sites [65]. Rocky Mountain bristlecone pine is moderately tolerant of saline soil [143], but not of salt spray [145]. In a greenhouse study, Rocky Mountain bristlecone pine seedlings showed high tolerance to ozone (20 pphm* and 30 pphm concentrations) compared to other pine species [144].

*parts per hundred million

OTHER USES:
Rocky Mountain bristlecone pine provides watershed and erosion protection on high-elevation sites [34,59,118]. Among subalpine communities of the Southwest, snowpack in open, Rocky Mountain bristlecone pine-dominated communities is usually the last to melt in spring [34,87].

Rocky Mountain bristlecone pine habitats are favored recreation sites [34]. The twisted, gnarly appearance of high-elevation Rocky Mountain bristlecone pines is aesthetically appealing [30,59].

As a long-lived conifer, Rocky Mountain bristlecone pine is important in dendrochronogy. Rocky Mountain bristlecone pine chronologies span 800 to 1,550 years BP [74,79]. The long chronologies obtained from Rocky Mountain bristlecone pines have been applied in other fields of science including climatology [23,24,77,78,79], atmospheric chemistry [52], geology [24], and archaeology [99,108,109].

Wood Products: Rocky Mountain bristlecone pine wood is not harvested commercially. Collecting Rocky Mountain bristlecone pine wood is prohibited in Arizona [4].

OTHER MANAGEMENT CONSIDERATIONS:
Rocky Mountain bristlecone pine is susceptible to parasite and fungus infections.

Damaging agents: Western spruce dwarf mistletoe (*Arceuthobium microcarpum*) infests Rocky Mountain bristlecone pines on the San Francisco Peaks. Low-elevation Rocky Mountain bristlecone pine are most susceptible to infection because western spruce dwarf mistletoe cannot survive at high elevations [94]. Elsewhere in Rocky Mountain bristlecone pine's range, southwestern dwarf mistletoe (*A. vaginatum* ssp. *crytopodum*) and lodgepole pine dwarf mistletoe (*A. americanum*) are occasional to rare parasites [55,56,58]. Southwestern dwarf mistletoe infection is most likely when Rocky Mountain bristlecone pine associates with infected interior ponderosa pines [58]. Rocky Mountain bristlecone pines are susceptible to heart-rot fungi, especially trees at low elevations [89].

Blister rust: Rocky Mountain bristlecone pine is susceptible to white pine blister rust [123], an exotic fungus that infects 5-needle white pines. A Rocky Mountain bristlecone pine in Great Sand Dunes National Monument, Colorado, was found infected with white pine blister rust in 2003. Limber pines in the area had shown symptoms of infection sine 1998 [19]. Rocky Mountain bristlecone pine's relative level of resistance to the rust is unclear. Seedling trials indicate that Rocky Mountain bristlecone pine may not be as susceptible to the rust as other North American 5-needle pines [62]. For example, in a New York old field study where 5-needle pines were planted near blister rust-infected European black currants (*Ribes nigrum*), Rocky Mountain bristlecone pine seedlings showed better resistance to infection than Eurasian 5-needle pine species, which have evolved with the rust and have high levels of genetic resistance to it [61]. In a review, Bingham [18] lists Rocky Mountain bristlecone pine as very resistant to white pine blister rust compared to other 5-needle white pines. However, resistance tests are based upon seedling trials and for Rocky Mountain bristlecone pine, usually small sample size [28]. In a seedling trial of 17 white pine species, Stephan [132] found a 66% infection rate of Rocky Mountain bristlecone pines: lower than other North American pines, including the closely related foxtail pine, but higher than Eurasian white pine species.

Whatever Rocky Mountain bristlecone pine's relative level of resistance in laboratory seedling trials, the fact remains: blister rust has already infected mature Rocky Mountain bristlecone pines in northern Colorado [146]. Other Rocky Mountain bristlecone pine populations are seriously at risk of infection. Arid climate has previously protected Rocky Mountain bristlecone pines from blister rust infection, but the potential for blister rust to spread into arid zones should not be underestimated. Blister rust's geographical range tends to spread only during wet years, when environmental conditions are favorable for infection of 5-needle pines [128]. In addition to infecting Rocky Mountain bristlecone pines in the Southwest, blister rust has also infected southwestern white pine (*Pinus strobiformis*) in the Sacramento Mountains of New Mexico [48,49].

Blister rust-infected white pines such as Rocky Mountain bristlecone pine may take from 2 years to decades to succumb, but infection is always fatal [63,64]. Gooseberries and currants (*Ribes* spp.) are the primary host of white pine blister rust. Life cycle of white pine blister rust is complex. Gitzendanner and others [50] and McDonald and Hoff [97] provide details of the rust's life history and ecology. Hoff [63] provides a diagnostic guide for recognizing symptoms of blister rust infection in white pines. There are no known methods of controlling blister rust [68]. Fungicide application, pruning infected tree branches, and/or removing *Ribes* spp. have neither eliminated nor controlled white pine blister rust [27,97], and such treatments have undesirable ecological effects [68].

Inventories are underway to detect and monitor levels of blister rust in Rocky Mountain bristlecone pine and other white pine stands, and to identify Rocky Mountain bristlecone pines with phenotypic resistance to blister rust. If blister rust outbreaks become severe, resistant Rocky Mountain bristlecone pines can be used as seed sources for transplanting programs that use blister rust-resistant seed stock [98,123]. For further information on management of white pine blister rust, see Samman and others [118], Tomback and others [139], and Sniezko and others [129].

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FEIS Home Page