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# Improving Plantation Establishment by Optimizing Growth Capacity and Planting Time of Western Yellow Pines

James L. Jenkinson

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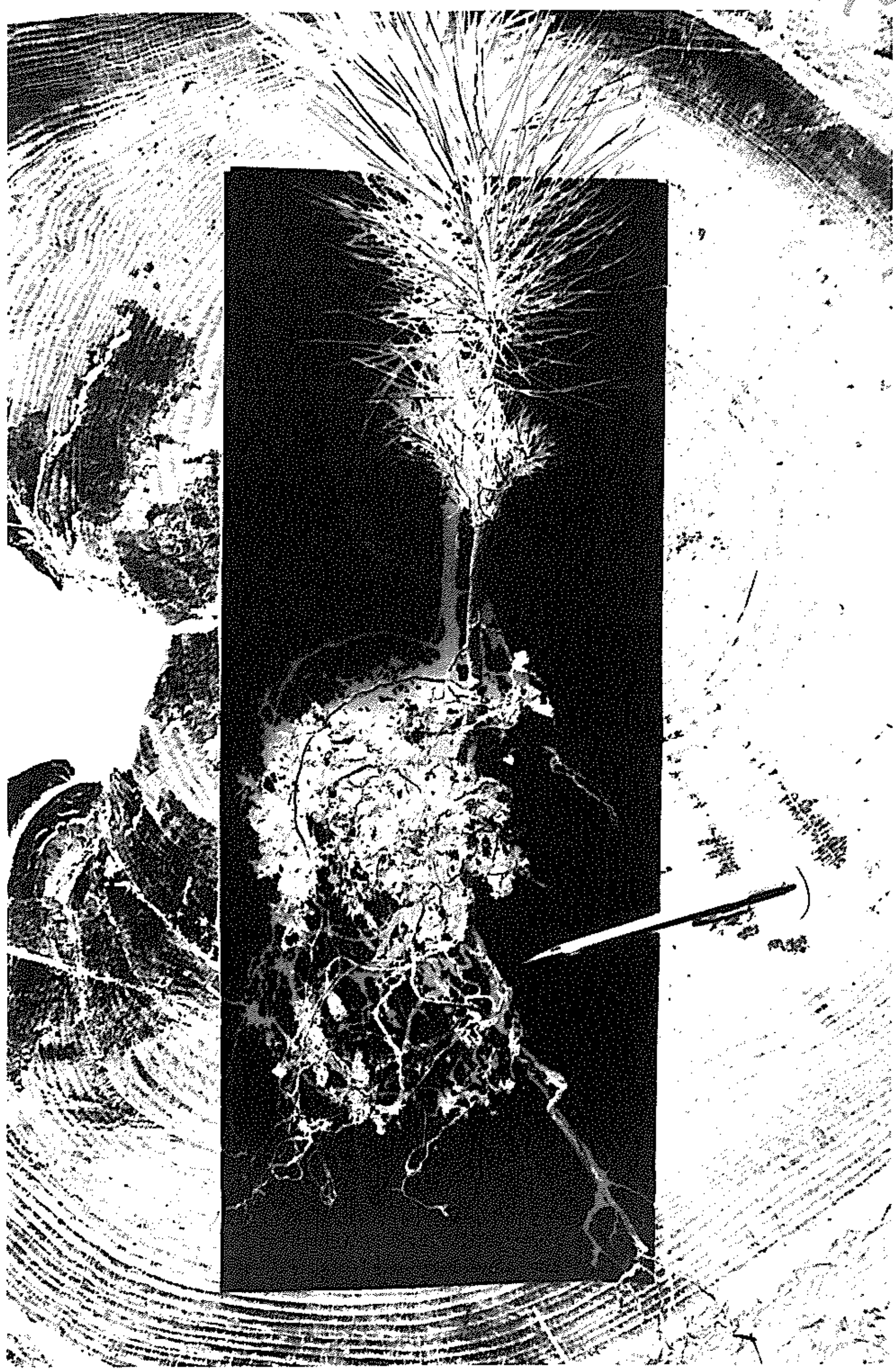

## Author:

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## IN BRIEF...

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*Retrieval terms: Pinus ponderosa, P. washoensis, P. jeffreyi,* genetic variation, genotype-environment interaction, progeny tests, seedling growth, seedling survival, artificial regeneration

Spring plantations are readily established on cleared sites in the California forests if the planted seedlings are dormant and have the capacity to resume rapid growth. Because California's commercial conifers range through several climatic regions, seedlings of different seed sources in the same nursery may vary markedly in their fall and winter development of dormancy and growth capacity. These innate seasonal patterns must be defined and exploited if nurserymen are to consistently deliver seedlings with highest survival potentials.

This paper describes research to define the seasonal patterns of growth capacity for seedlings of 27 sources of western yellow pines raised in a nursery in the western Sierra Nevada, at the Forest Service Institute of Forest Genetics near Placerville. Coincident research explored the relation of field survival to planting time and site environment. The effect of planting time was assessed for sources from five western states by transplanting seedlings in winter and in spring to a cleared site below snow line. The effect of site environment was evaluated for selected sources from the northern Sierra Nevada by planting seedlings in spring on an elevational array of cleared sites, three west and one east of the Sierra crest. The findings apply directly to lifting schedules in the Forest Service Placerville Nursery and to planting schedules on the National Forests that the nursery serves.

In this survey of the western yellow pines, typical populations of California ponderosa, Jeffrey, and Washoe pines were sampled in four climatic regions—coastal California, western Sierra Nevada, eastern Sierra-Cascade, and southern California. Typical ponderosa pine was also sampled in continental climates in southern Oregon, eastern Nevada, central Arizona, and southeastern Wyoming.

Over a 4-year period, seeds of 6 to 9 of the 27 sources were sown in the nursery each spring. Three sources were sown twice to provide a base for comparing sources tested in different years. To monitor top and root growth capacity of each source through the winter season, first-year seedlings were sampled monthly and measured for new growth after 21 days in a standard warm environment. In the field survival tests, first-year seedlings were outplanted from the first and second sowings, and final survivals were recorded the next winter or spring.

There were large differences among sources in seedling root growth capacity (RGC), and the seasonal patterns of RGC were of four distinct types: fall-peak, winter-peak, plateau, and bimodal. That is, depending on source, seedling RGC peaked in fall only, in midwinter only, continuously from fall through winter, or in fall and again in winter. All four patterns were found in ponderosa pine from both outside and inside California, while bimodal patterns characterized Washoe pine and Jeffrey pine.

Midwinter-peak patterns typified ponderosa pine from coastal California, western Sierra Nevada, and eastern Sierra-Cascade regions, and Jeffrey pine from ultramafic soil in the western Sierra Nevada. Plateau patterns characterized ponderosa pine from the western Sierra foothills, Lake Tahoe Basin, and central Arizona. Fall-peak patterns were evident in ponderosa pine from the western Sierra pine belt and eastern Nevada. Bimodal patterns typified both ponderosa pine and Jeffrey pine from southern California, Washoe pine and Jeffrey pine from east of the Sierra crest, and ponderosa pine from southeastern Wyoming.

Within regions, shifts in the pattern for ponderosa pine apparently reflected elevational or latitudinal gradients in temperature and moisture regimes. In two regions, plateau and winter-peak patterns anchored the ends of the gradients. Along the slope of the western Sierra Nevada, the time needed to develop peak RGC increased with elevation of the parent stand, and duration of peak level decreased. East of the Sierra-Cascade crest, the time needed to reach peak RGC increased with latitude of the parent stand, and duration of peak level again decreased. In the San Gabriel Mountains of southern California, the pattern shifted from typically bimodal toward a late-winter peak with increasing elevation of the parent stand.

Apart from these environmental gradients, the seasonal pattern bore little apparent relation to the climate at seed origin. Each pattern type appeared in seedlings from two to four climatic regions, and three patterns appeared in each of two regions.

The seasonal pattern of seedling top growth capacity was a sigmoid curve, and for every source the chilling requirements for renewed top growth were met by midwinter. To enable bud swell, ponderosa pine from west of the Sierra crest required the least chilling, while Washoe pine and Jeffrey pine required the most. For rapid shoot extension, Washoe pine and ponderosa pine from continental climates required the least chilling, while ponderosa and Jeffrey pines from southern California required the most.

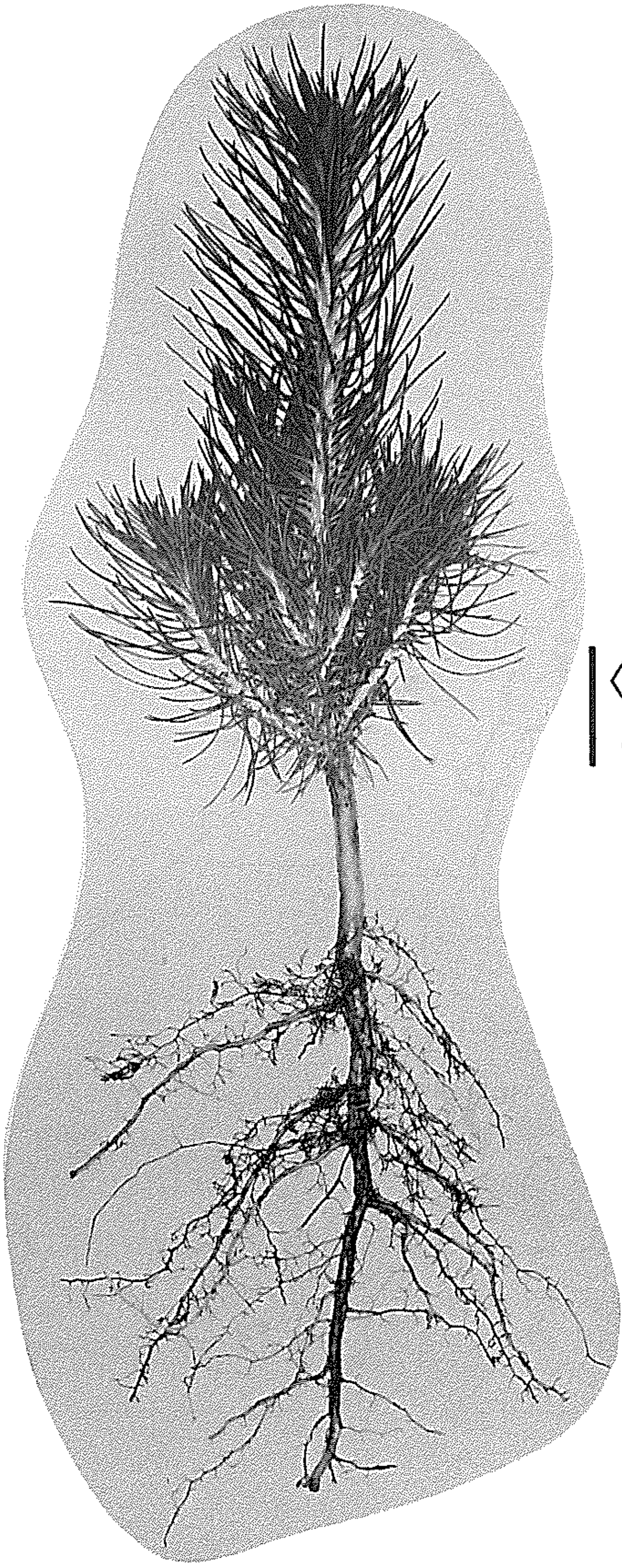
Both seed source and planting time affected seedling survival. Survival was significantly less in midwinter than in spring plantings, and consistently higher for California than for Arizona and Wyoming sources. California sources are adapted to summer drought, and thus survived better than the continental sources which normally receive summer rains. Seedlings planted in midwinter had root growth capacities two to three times higher than seedlings planted in spring, but in cold soil planted seedlings do not elongate roots, do undergo high water stress, and continually expend stored reserves. The expected results are large decreases in RGC before the soil warms in spring, and high seedling mortality during the summer drought.

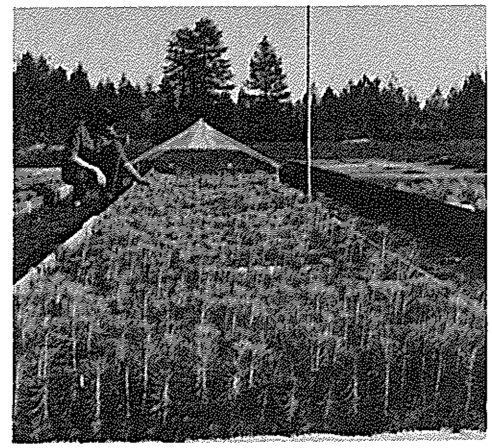
Site environment and seed source had little or no influence on seedling survivals in spring plantations. Survivals of California ponderosa and Jeffrey pines, from parent stands at 500 to 8200 ft of elevation, were uniformly high on sites ranging from 1900 to 6600 ft. Evidently, plantation establishment is assured on cleared sites if dormant seedlings are lifted with moderate to high RGC, are properly stored, and are planted when the soils are warming sufficiently to enable water uptake and root elongation.

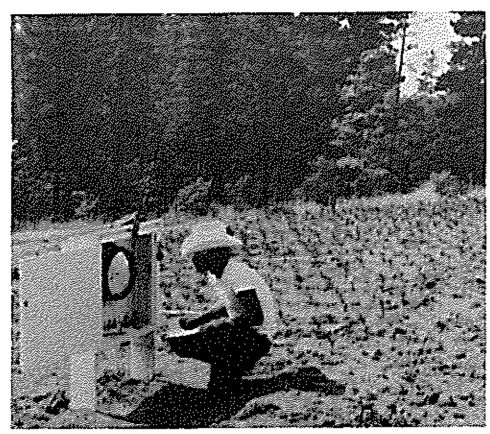
The innate seasonal patterns of RGC indicated optimum lifting schedules for particular sources of seedlings raised in the Placerville Nursery. The data were sufficient to identify specific lifting times for most sources from the northern Sierra Nevada, Cascade Range, Modoc Plateau, and southern California, but were insufficient or lacking for the Klamath Mountains, Coast Ranges, and southern Sierra Nevada.

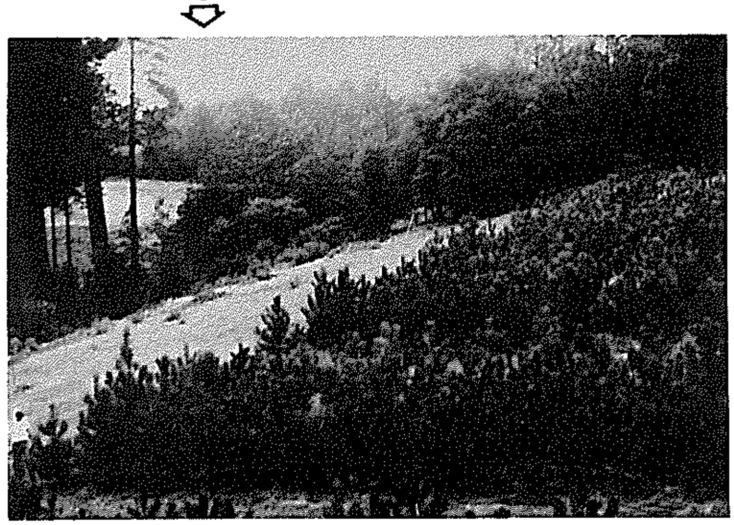
High survivals in the elevational array of field tests identified planting times that enhance seedling establishment. Using these data, and recognizing that cold soil and evaporative stress limit the spring period when seedlings can be safely planted on a particular site, a planting schedule was prescribed for elevations ranging from 500 to 7000 ft in the central Sierra Nevada. Similar prescriptions, but different in calendar dates, may apply throughout California.

In essence, the key to plantation establishment for a particular seed source is knowing when to lift the seedlings in the nursery and when to plant them in the field.









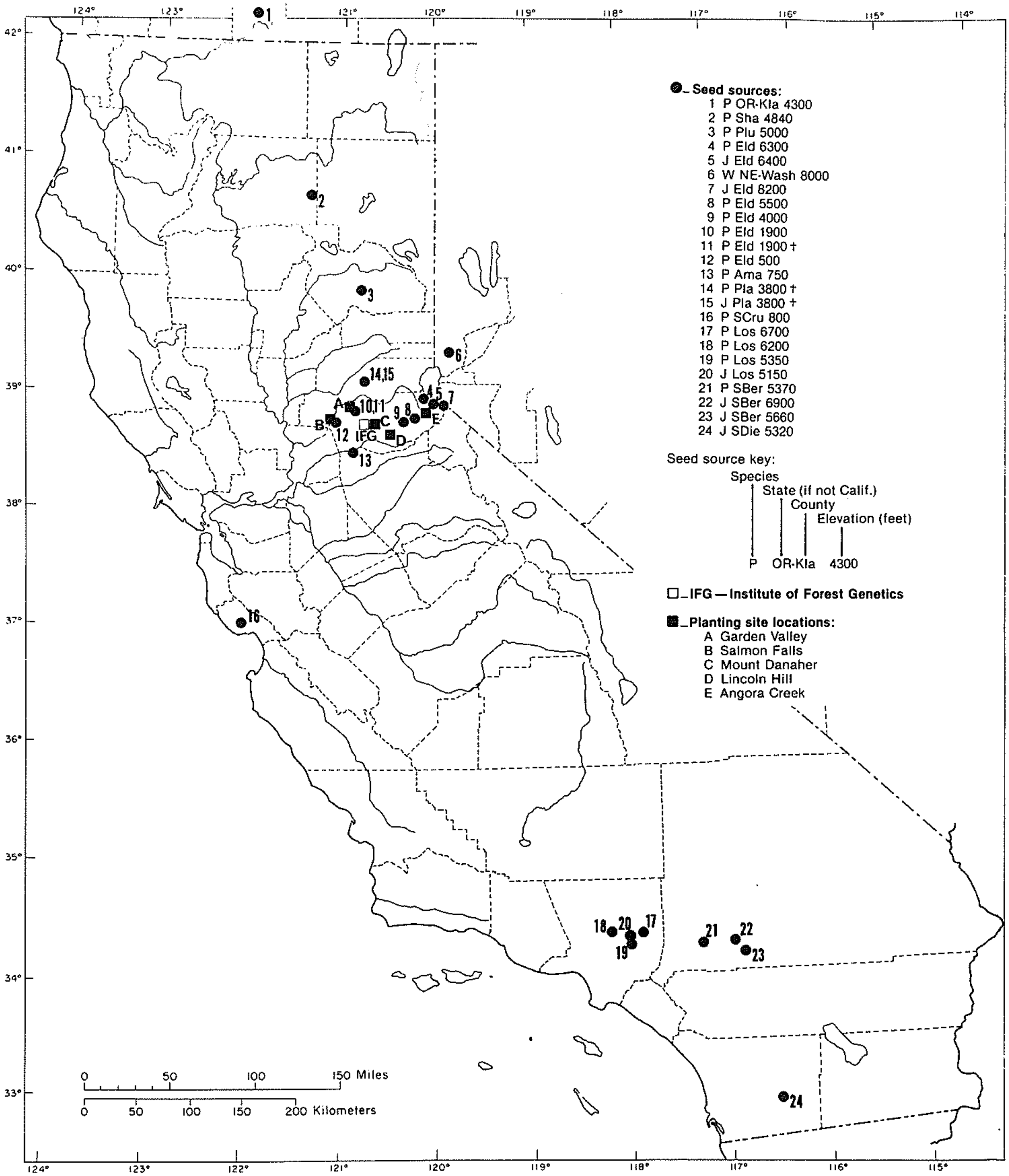



**Figure 1**—To investigate seedling growth capacity and field survival, 27 sources of ponderosa (P), Washoe (W), and Jeffrey (J) pines were grown in the Institute of Forest Genetics nursery, on Fruit Ridge in the western Sierra Nevada. For seed source description, see *table 1.* Three sources not shown were in Nevada, Arizona, and Wyoming.

Eight of California's commercially important conifers are commonly regenerated by planting bare-root seedlings: ponderosa, Jeffrey, and sugar pines (*Pinus ponderosa* Laws., *P. jeffreyi* Grev. & Balf., *P. lambertiana* Dougl.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), white and red firs (*Abies concolor* [Gord. & Glend.] Lindl., *A. magnifica* A. Murr.), incense cedar (*Libocedrus decurrens* Torr.), and big tree (*Sequoiadendron giganteum* [Lindl.] Buchholz). Plantation establishment of every species has varied widely, and it still ranges from mostly failure to routine success. The recent congressional directives to reforest unstocked timberland, i.e., the Supplemental National Forest Reforestation Fund Act and National Forest Management Act of 1976 (USDA Forest Serv. 1978), and yearly increases in regeneration cutting are now requiring the National Forests to triple the acreage that is planted annually. To secure plantation establishment quickly and consistently, foresters must understand the seedling responses to both the nursery and planting site environments.

Universally, bare-root seedlings that survive and grow best sort into the average and large sizes. They have top-to-root ratios under 1.5, and they are free of disease. To produce such "plantable" seedlings, nurserymen must successfully integrate soil management, seed treatment and sowing, mycorrhizal inoculation, irrigation, fertilization, undercutting, and pathogen control. However, optimum cultural regimes and morphological grades alone do not guarantee field survival. To insure plantation establishment, the physiological conditioning requirements of the seedlings must be met at the nursery, the planted seedlings must have adequate growth capacities, and the planting site environments must support seedling function and growth (Tinus 1974).

In most of the California forests, spring is the accepted time to plant bare-root seedlings. To survive in the field, newly planted seedlings must be dormant to minimize transpirational losses of water, and cold-hardy to endure frosts. Further, they must grow roots to reach enough available water to sustain top growth, form terminal buds, and avoid lethal stress during the summer drought.

In California's forest tree nurseries, it is largely the fall and winter climate that develops the seedlings' requisite physiological condition for spring outplanting (Stone and others 1963). Both seedling dormancy in the nursery and the amounts of growth that lifted seedlings can produce in a warm environment are closely related to the seedlings' prior exposure to cold (Krugman and Stone 1966, Stone and Jenkinson 1971).

Nurserymen fix the state of dormancy and the root and top growth capacity of the seedlings they harvest by their choice of the particular dates when those seedlings are lifted and stored. Silviculturists select the planting dates, and thereby determine the soil and air temperature-moisture regimes that planted seedlings encounter during the first critical weeks in the field. The initial field environment may decisively control the expression of growth capacity, and consequently seedling survival (Stone and Jenkinson 1970, Stone and Schubert 1959, Stone and others 1962, Ursic and others 1966).

California's conspicuous diversity of forest climate, physiography, and vegetation warns of large differences between species and between seed sources in how the nursery environment affects seedling dormancy and growth capacity. In the western yellow pines—ponderosa, Washoe (*P. washoensis* Mason & Stockwell), and Jeffrey—and in Douglas-fir, the seed source response to nursery environment creates major variation in the growth capacity of dormant seedlings (Jenkinson 1976, 1978).

This paper reports the inherent seasonal patterns of seedling growth capacity for the western yellow pines, and describes the influences of seed source, planting time and site environment on seedling survival in the field. The findings apply directly to the Forest Service Placerville Nursery, and to the planting operations of its clientele, the National Forests of California.

## METHODS AND MATERIALS

Seed sources were deliberately chosen to sample a wide range of yellow pine environments in the Western United States, and especially California (*fig. 1*). During the period from 1972 to 1976, seedlings of 27 sources were raised in a nursery in the western Sierra Nevada and lifted for specific studies after one growing season.

To evaluate the development of growth capacity, seedlings of every source were sampled periodically during their first winter season, and tested for growth in a warm standard environment (growth capacity study). To determine the effect of planting time on field survival, seedlings of 13 sources were outplanted in winter and in spring on a cleared site below snow line in the western Sierra Nevada (planting time study). To assess the effect of planting site environment on survival, seedlings of 7 local sources were planted in spring on cleared sites west and east of the Sierra Nevada crest (site environment study).

All studies were conducted by staff at the Institute of Forest Genetics, Pacific Southwest Forest and Range Experiment Station, near Placerville *(fig. 1)*. The Institute nursery and the Placerville Nursery are both located on Fruit Ridge, at an elevation of about 2750 ft (840 m). They are 1 mile (1.6 km) apart and have identical climates and soils.

## Seed Sources

The seed sources were selected between latitudes 32° and 43°N, in forests that typify the species ranges (Critchfield and Little 1966, Griffin and Critchfield 1976) and vegetational associations in seven climatic regions *(table 1, fig. 1)*. Selection of ponderosa pine was also guided by geographic variation in the monoterpene composition of standing trees; sources were chosen in four of five type regions and two of four transition zones (Smith 1977, Sturgeon 1976).

To represent major climatic regions outside California, ponderosa pine was selected in southeastern Wyoming, central Arizona, and eastern Nevada. The Wyoming and Arizona sources are in continental climates with no drought and with spring drought, respectively (Beschta 1976; U.S. Dep. Comm. 1954, 1959, 1964a, 1965c). The Nevada source gets scattered thundershowers and is largely riparian (U.S. Dep. Comm. 1960, 1965a).

To provide a latitudinal transect in continental climates with summer drought, ponderosa pine was selected in four separate areas east of the Cascade Range and Sierra Nevada crests, from southern Oregon to Lake Tahoe (U.S. Dep. Comm. 1963; 1964b,c; 1965b). Jeffrey pine at the south end of the transect and both Washoe and Jeffrey pines in the adjacent Carson Range were chosen for comparison with ponderosa pine.

To sample a temperature-moisture gradient associated with elevation, ponderosa pine was selected at 500, 1900, 4000, and 5500 ft along or near South Fork of the American River, in the western Sierra Nevada (U.S. Dep. Comm. 1964b,c). Stands were also sampled on unusual and typically xeric sites, including ponderosa pine on an island of infertile, ultramafic soil in the pine phase of mixed conifer forest, ponderosa pine in the foothill woodland of the Cosumnes River drainage, and a mixed stand of ponderosa and Jeffrey pines in a large area of ultramafic soil surrounded by typical mixed conifer forest.

For a maritime climate, ponderosa pine was selected in the Santa Cruz Mountains of coastal California. Except for the frequent ocean fogs, the summer drought there resembles that in the western Sierra foothills (Griffin 1964; U.S. Dep. Comm. 1964b,c).

Finally, in southern California, a region where arid climates severely challenge regeneration (U.S. Dep. Comm. 1964b,c), ponderosa pine was selected at three elevations in the San Gabriel Mountains and in one area in the San Bernardino Mountains. Jeffrey pine was selected in the San Gabriel Mountains, in two areas in the San Bernardino Mountains, and in the Laguna Mountains of the southern Peninsular Ranges.

Cones were collected from the upper crown of 10 or more well-distributed trees of every source.[1] The collection from each parent tree, hereafter termed a family, was handled separately. The seeds were extracted from sun-dried cones, cleaned to eliminate the hollow and incompletely filled seeds, air-dried at ambient room temperatures, and stored at 1°C (34°F) or at −18°C (0°F).

## Nursery Procedures

Seeds were stratified 60 days at 1°C (34°F). The treated seeds were sown in early May, in beds measuring 50 ft (15 m) long and 5 ft (1.5 m) wide. Families were sown in plots across the bed, in spots set 2.4 inches (6 cm) apart within rows spaced 6 inches (15 cm) apart. After sowing, the beds were mulched with a thin layer of perlite and drenched with a Captan suspension to control damping-off fungi.

Germination was uniformly rapid, and seedling emergence ranged from 95 to 100 percent for most families. The seedlings were thinned to $20/ft^2$ in August, and were watered twice weekly until heavy rains in the fall. To prevent seedling deficiencies in nitrogen and phosphorus, the nursery soil, an Aiken clay loam, was fertilized during bed preparation and in midsummer with a pelletized ammonium phosphate sulfate (NP, 16-20) at rates of 100 lb N/acre (112 kg N/ha).

To define the natural periods of seedling growth and dormancy, the times when visible top and root

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[1]The Wyoming, Arizona, Nevada, and Oregon collections were supplied by Ralph A. Read, Rocky Mountain Forest and Range Experiment Station, Lincoln, Nebraska; John A. Pitcher, formerly of the Southwestern Region, Forest Service, Albuquerque, New Mexico, and now with the Southeastern Forest Experiment Station, Starkville, Mississippi; Richard H. Smith, Pacific Southwest Forest and Range Experiment Station, Berkeley, California; and Brian D. Cleary, formerly of Weyerhaeuser Co. and now with Oregon State University, Corvallis. The Modoc Plateau and southern California collections were supplied by John Alden, formerly of the Pacific Southwest Region, Forest Service, Yreka, California, and Bureau of Land Management, U.S. Department of Interior, Portland, Oregon; and Gaylord K. Parks, Pacific Southwest Region, Forest Service, Placerville, California.

Table 1—*Seed sources of ponderosa (P), Washoe (W), and Jeffrey (J) pines selected in seven climatic regions in the western United States*

| Forest area and seed source[1] | Stand locality and county | Tree seed zone[2] | Elevation | | Local arborescent associates[3] |
|---|---|---|---|---|---|
| | | | *Feet* | *Meters* | |
| | **East Continental Divide** | | | | |
| Laramie Range, Wyoming | | | | | |
| P WY-Lar 7700 | Pole Mountain-Buford, Laramie | — | 7700 | 2347 | F |
| | **Colorado Plateau** | | | | |
| Mogollon Mesa, Arizona | | | | | |
| P AR-Coco 7000 | Chevelon Ranger Stn., Coconino | 150 | 7000 | 2134 | JuSc,JuDe,QuGa |
| | **Basin and Range** | | | | |
| Snake Range, Nevada | | | | | |
| P NE-Whi 7500 | Lehman Creek, White Pine | — | 7500 | 2286 | AC,PiEn,PsMz,M,JuOs, JuSc |
| | **Eastern Sierra-Cascade** | | | | |
| Cascade Range, Oregon | | | | | |
| P OR-Kla 4300 | Aspen Lake, Klamath | 701 | 4300 | 1311 | AC |
| Modoc Plateau | | | | | |
| P Sha 4840 | Hat Creek Rim, Shasta | 732 | 4840 | 1475 | JuOc,AC,LiDe,L |
| Northern Sierra Nevada | | | | | |
| P Plu 5000 | Spring Garden, Plumas | 523 | 5000 | 1524 | L,LiDe,PsMz,QuKe |
| Lake Tahoe Basin | | | | | |
| P Eld 6300 | Emerald Bay, El Dorado | 772 | 6300 | 1920 | LiDe,L,AC,QuKe,J |
| J Eld 6400 | South Lake Tahoe, El Dorado | 772 | 6400 | 1951 | AC,L,LiDe,My |
| Carson Range | | | | | |
| W NE-Wash 8000 | Galena Creek, Washoe | 772 | 8000 | 2438 | J,My,Mt,AM |
| J Eld 8200 | High Meadows, El Dorado | 881 | 8200 | 2499 | My,AM,Mt,Al,JuOc |
| | **Western Sierra Nevada** | | | | |
| Western Sierra Nevada | | | | | |
| P Eld 5500 | Wrights Lake Road, El Dorado | 526 | 5500 | 1676 | LiDe,L,AC,PsMz,QuKe,J |
| P Eld 4000 | Sugarloaf, El Dorado | 526 | 4000 | 1219 | L,PsMz,QuKe,LiDe,AC |
| P Eld 1900 | Garden Valley, El Dorado | 526 | 1900 | 579 | L,LiDe,QuKe,QuCh |
| P Eld 1900† | Johntown Creek, El Dorado | 526 | 1900 | 579 | S,LiDe |
| P Eld 500 | Salmon Falls, El Dorado | 526 | 500 | 152 | S,QuWi,QuDo,QuKe |
| P Ama 750 | Plymouth-Purcell, Amador | 526 | 750 | 229 | S,QuWi,QuDo |
| P Pla 3800† | Sugar Pine Stn., Placer | 525 | 3800 | 1158 | J,LiDe,L |
| J Pla 3800† | Sugar Pine Stn., Placer | 525 | 3800 | 1158 | P,LiDe,L |
| | **Coastal California** | | | | |
| Santa Cruz Mountains | | | | | |
| P SCru 800 | Mount Hermon, Santa Cruz | 097 | 800 | 244 | QuAg,ArMz |
| | **Southern California** | | | | |
| San Gabriel Mountains | | | | | |
| P Los 6700 | Islip Saddle, Los Angeles | 993 | 6700 | 2042 | J,L,AC |
| P Los 6200 | Mount Gleason, Los Angeles | 993 | 6200 | 1890 | J,L,AC |
| P Los 5350 | Charlton Flat, Los Angeles | 993 | 5350 | 1631 | J,Cl |
| J Los 5150 | Chilao Creek, Los Angeles | 993 | 5150 | 1570 | P,Cl |
| San Bernardino Mountains | | | | | |
| P SBer 5370 | Lake Arrowhead, San Bernardino | 994 | 5370 | 1637 | L,QuKe,AC,LiDe |
| J SBer 6900 | Big Bear Lake, San Bernardino | 994 | 6900 | 2103 | L,AC |
| J SBer 5660 | Santa Ana River, San Bernardino | 994 | 5660 | 1725 | P,Cl |
| Peninsular Ranges | | | | | |
| J SDie 5320 | Laguna Mountains, San Diego | 998 | 5320 | 1622 | QuKe,Cl,LiDe |

[1]For source designation, see *figure 1;* † indicates source is native on infertile, ultramafic soil.

[2]Forest tree seed collection zones (Schubert and Pitcher 1973; USDA Forest Serv. 1966, 1969).

[3]
P: *Pinus ponderosa* Laws.
J: *P. jeffreyi* Grev. & Balf.
S: *P. sabiniana* Dougl.
Cl: *P. coulteri* D. Don
L: *P. lambertiana* Dougl.
My: *P. contorta* Dougl.
Mt: *P. monticola* Dougl.
Al: *P. albicaulis* Engelm.
M: *P. monophylla* Torr. & Frem.
W: *P. washoensis* Mason & Stockwell
F: *P. flexilis* James
QuGa: *Quercus gambelii* Nutt.
QuKe: *Q. kelloggii* Newb.
QuDo: *Q. douglasii* Hook. & Arn.
QuWi: *Quercus wislizenii* A. DC.
QuAg: *Q. agrifolia* Nee
QuCh: *Q. chrysolepis* Liebm.
JuOc: *Juniperus occidentalis* Hook.
JuSc: *J. scopulorum* Sarg.
JuOs: *J. osteosperma* (Torr.) Little
JuDe: *J. deppeana* Steud.
AM: *Abies magnifica* A. Murr.
AC: *A. concolor* (Gord. & Glend.) Lindl.
PsMz: *Pseudotsuga menziesii* (Mirb.) Franco
LiDe: *Libocedrus decurrens* Torr.
ArMz: *Arbutus menziesii* Pursh
PiEn: *Picea engelmannii* Parry

growth ceased in the fall and resumed in spring were noted. To relate seedling growth, dormancy, and growth capacity to nursery climate, soil and air temperatures were recorded continuously from September to May. A hygrothermograph and min-max thermometers were housed in a standard weather shelter, and soil thermograph probes were set at 3 and 6 inches (7.5 and 15 cm) below the bed surface to sense the zone where seedling roots were concentrated.

### Growth Capacity and Planting Time Studies

Seeds of six to nine different sources were sown in 1972, 1973, 1974, and 1975. Sources in the first two sowings represented ponderosa pine from six climatic regions (southern California excepted) and all three species of western yellow pines from the central Sierra Nevada and Carson Range. Sources in the last two sowings were ponderosa and Jeffrey pines from the western Sierra Nevada and southern California. To compare sources tested in different years, three sources were sown twice: P AR-Coco 7000 in 1972 and 1973, P Eld 1900 in 1973 and 1974, and P Eld 4000 in 1974 and 1975 (see *fig. 1* for the key to source designations).

The annual sowing design was a randomized block with eight replications. Ten families per source were sown in separate, quarter-row family plots, and the seedlings were thinned to 10 per plot.

### Site Environment Study

Seeds of seven to eight sources from the western Sierra Nevada and Lake Tahoe Basin, representing ponderosa pine from 500 to 6300 ft and Jeffrey pine from 3800 to 8200 ft, were sown in 1972 and 1973. Five of these sources were also included in the planting time study: P Eld 500, 1900, 6300; J Eld 6400, 8200.

The annual sowing design was a randomized block with four replications. Ten families per source were sown in separate, full-row family plots, and the seedlings were thinned to 48 per plot.

## Growth Capacity Evaluation

Seedlings in the current nursery crop were sampled five or six times from October to March. A randomly selected block was lifted each time, and the roots of the lifted seedlings were pruned 9 inches (23 cm) below the cotyledon nodes, roughly 8 inches (20 cm) below ground line *(fig. 2)*.

For every source, three sets of 10 typical seedlings, each from a different family, were planted in separate, stainless steel containers measuring 3 by 15 by 12 inches deep (7.5 by 37.5 by 30.5 cm). The seedlings were planted with a moist soil mix of 1:1:1:1 Aiken clay loam, sand, perlite, and finely shredded redwood bark, and were thoroughly watered once. To retain soil and speed irrigation, the container drainports were capped inside with 10-mesh brass screen bent to form an inverted channel 1 inch wide and 0.8 inch deep (2.5 by 2 cm). After watering, the containers were drained overnight, sealed with rubber stoppers, and mulched with white sand.

The watertight containers were immersed to the rim in a row of five thermostatically controlled stainless steel water baths housed in an airconditioned greenhouse. Every source was positioned in three different baths, in a randomized block design with three replications.

The soil temperature was maintained at 20°C (68°F). Air in the greenhouse was circulated continuously, and was held below 27°C (81°F) during the day and near 15°C (59°F) at night. The natural photoperiod was extended to 16 hours with an overhead bank of mercury-phosphor lights (Bickford and Dunn 1972, Veen and Meijer 1962). The lights were on from 6 to 8 a.m. and from 4 to 10 p.m., and gave 35 $w/m^2$ at the seedling level. To compensate for seasonal differences in sunlight and heat load, the greenhouse was shaded with a 53 percent shade screen for tests started in October and March.

After 21 days, or 24 days (1972-1973 only), the seedlings were washed free of soil, and the following data were promptly recorded for each seedling:

- Length of every new root elongation of 1.5 cm or more (to the nearest 0.5 cm).
- Number of roots with new growth between 0.2 and 1.5 cm.
- Growth activity of the top, using a top growth index:
  - 1 = leader (terminal bud) and fascicle buds dormant
  - 2 = fascicle buds swelling
  - 3 = 2 with color change in the terminal centimeter of leader
  - 4 = 2 with leader elongating
  - 5 = leader and needles elongating
- Length of the zone of leader elongation, to the nearest millimeter.
- Stem diameter at 1 cm below the cotyledon node.

Differences in root growth between sources and between lifting dates for every source were established by least significant difference procedures, and by Duncan's new multiple range test ($p = 0.05$, Steel and Torrie 1960).

## Field Survival Evaluation

Typical pine sites, four west and one east of the Sierra Nevada crest, were chosen for testing seedling survival *(table 2)*. All of the sites are in El Dorado County *(fig. 1)*, in forest areas that were

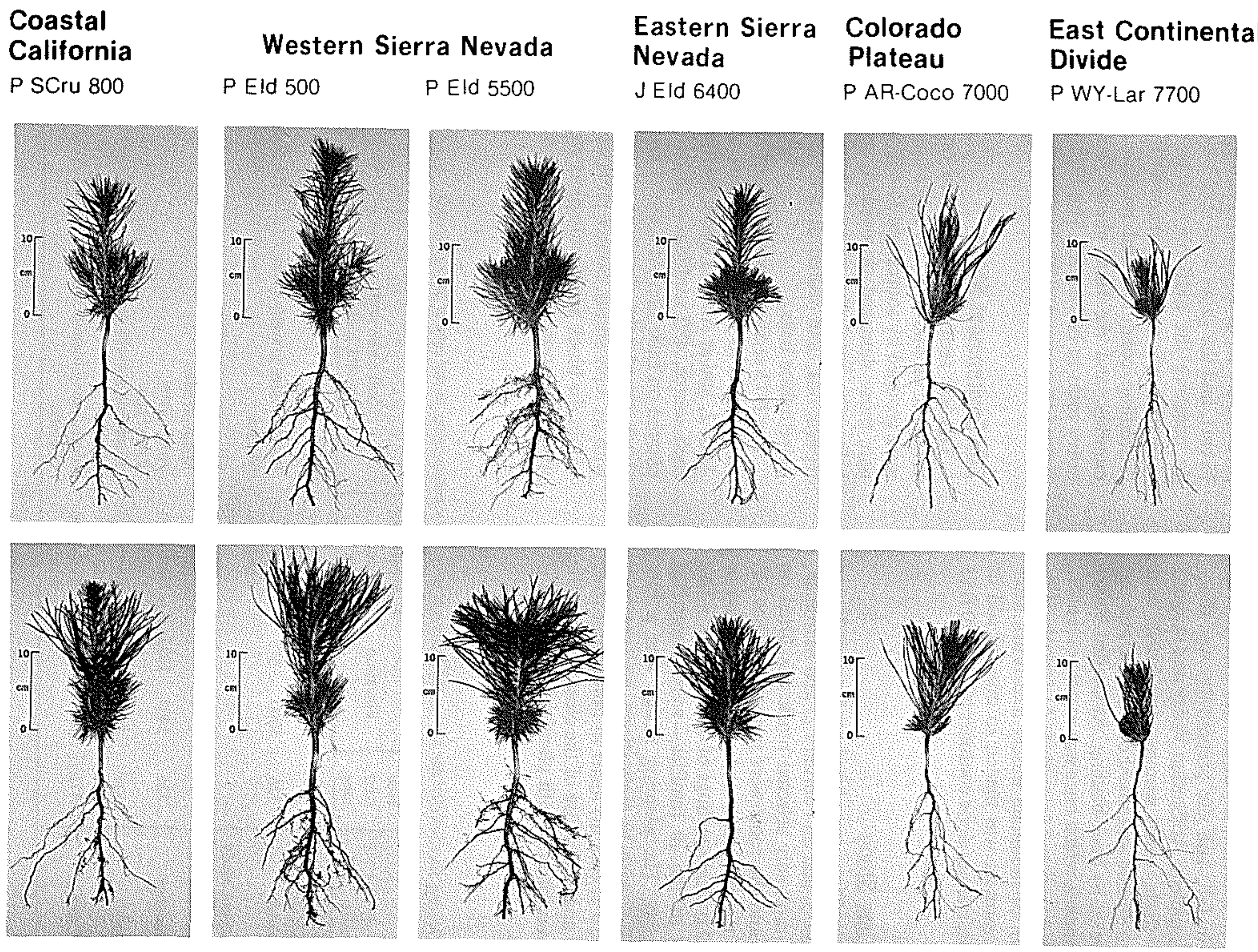



**Figure 2**—Typical seedlings of western yellow pines, lifted in the nursery and root-pruned 23 centimeters below the foliage, were tested for growth capacity and field survival.

either clearcut, cleared for agriculture, or burned by wildfire many years ago.

Site preparation at Salmon Falls was done by hand in spring; the thick grass sod was scalped to bare mineral soil, to make planting spots about 1 $yd^2$ (1 $m^2$). In contrast, the other sites were cleared by tractor in fall, and site preparation was thorough and complete. At Garden Valley and Angora Creek, the slash, small stumps, and brush root crowns were pushed and raked off the site, and the soil was leveled by back-blading. At Garden Valley and Mt. Danaher, which once was in pear orchards, the soil was disked and rotovated. At Lincoln Hill, the regrowth of mountain misery and brush after herbicide treatment was bladed to mineral soil in strips 8 ft wide along slope contours roughly 10 ft (3 m) apart.

## Planting Time Study

The test seedlings were lifted on January 23 and March 14, 1973, and on February 27 and March 28, 1974. One randomly selected block was lifted on each date, and the roots were pruned 9 inches (23 cm) below the cotyledon nodes. The same day or the next, 50 typical seedlings of every source—five from each of the 10 families—were planted at Garden Valley. The planting design was a randomized block with 10 replications, and seedlings were spaced 1 ft (0.3 m) apart in family-plot rows spaced 2 ft apart. Because of the close spacing, the seedlings were planted with planting bars.

The Garden Valley site was chosen because the summer is always hot and the drought normally extends from April to November. To monitor the site environment, a soil thermograph and two rain gages were installed with the first planting. The probes were set at depths of 3 and 6 inches (7.5 and 15 cm), and the gages were read after every storm. To conserve the available soil water, competing vegetation was removed whenever it appeared.

Seedling condition and mortality were scored monthly, and the final checks were made after heavy rains in November. The 1973 plantings were cleared to accommodate the 1974 plantings.

## Site Environment Study

The test seedlings were lifted on February 24, 1973, and on March 11, 1974. Seedlings of all blocks were grouped by source and family, culled to eliminate those damaged or atypical, pruned 9 inches below the cotyledon nodes, sorted into planting replications, and stored at 1 °C (34 °F) in sealed polyethylene bags.

The 1973 seedlings were planted at Salmon Falls on March 5 to 9, at Mt. Danaher on March 29 to April 2, and at Angora Creek on May 15 to 17. For each source, 480 seedlings—48 per family—were planted on each site. At Salmon Falls and Angora Creek, the planting design was a randomized block with six replications. Source plots were randomized within the block and family plots were randomized within the source. Seedlings were planted two per

Table 2—*Planting sites selected for testing field survival of western yellow pines in the central Sierra Nevada*

| Name of study and planting site | Tree seed zone | Elevation | | Aspect and slope (pct.) | Soil series and parent rock[1] | Local arborescent associates[2] |
|---|---|---|---|---|---|---|
| | | *Feet* | *Meters* | | | |
| Planting time study | | | | | | |
| Garden Valley | 526 | 1900 | 579 | South<br>9 to 15 | Boomer-Sites gravelly loam<br>Marine | P,L,PsMz,LiDe,QuWi,<br>QuKe,QuCh |
| Site environment study | | | | | | |
| Salmon Falls | 526 | 500 | 152 | North<br>9 to 30 | Auburn very rocky silt loam<br>Metavolcanic | P,S,QuWi,QuDo,QuKe |
| Mount Danaher | 526 | 3400 | 1036 | Northwest<br>3 to 15 | Aiken loam<br>Pyroclastic | P,L,PsMz,AC,LiDe,<br>QuKe,ArMz |
| Lincoln Hill | 526 | 4500 | 1372 | South<br>9 to 30 | Josephine gravelly loam<br>Marine | P,L,PsMz,AC,LiDe,<br>QuKe |
| Angora Creek | 772 | 6600 | 2012 | Northwest<br>0 to 5 | Meeks stony loamy coarse sand<br>Granitic | J,AM,My,AC |

[1]Calif. Div. Mines and Geol. 1971; Rodgers 1974a,b.

[2]
P: *Pinus ponderosa* Laws.
J: *P. jeffreyi* Grev. & Balf.
S: *P. sabiniana* Dougl.
L: *P. lambertiana* Dougl.
My: *P. contorta* Dougl.
AM: *Abies magnifica* A. Murr.
AC: *A. concolor* (Gord. & Glend.) Lindl.
QuKe: *Quercus kelloggii* Newb.
QuDo: *Q. douglasii* Hook.& Arn.
QuWi: *Q. wislizenii* A. DC.
QuCh: *Q. chrysolepis* Liebm.
LiDe: *Libocedrus decurrens* Torr.
ArMz: *Arbutus menziesii* Pursh
PsMz: *Pseudotsuga menziesii* (Mirb.) Franco

spot in four-spot family rows, in spots spaced 6 by 6 ft (1.8 m). At Mt. Danaher, the design was a randomized block with 24 replications. Seedlings again were planted two per spot, but in single-spot family plots spaced 8 by 8 ft (2.4 m).

The 1974 seedlings were planted at Lincoln Hill on April 17 to 19. There, 320 seedlings—32 per family—were planted for each source. The design was a randomized block with eight replications. Source rows were centered in the bladed strips, with seedlings planted two per spot in two-spot family rows. Spacing was 5 ft (1.5 m) within and 10 ft (3 m) between rows.

At Salmon Falls, the soil was very rocky and the planting had to be done with planting bars. Soils were less rocky on the other sites, and the planting holes were easily made with powered soil augers.

During the first summer, competing vegetation was allowed to develop only at Salmon Falls. There, new grasses soon formed a dense stand, and the scalped spots were not treated until the following spring. Pocket gophers invaded every planting, but were controlled by trapping whenever fresh activity was found.

Seedlings on every site had high survival and good growth to midsummer. Seedlings on the best site, at Mt. Danaher, were basin-watered once in late July to sustain their rapid growth, as further mortality there was judged unlikely.

All of the plantings were scored at frequent intervals until the winter storms, and were scored again in spring and fall of the second year.

## RESULTS

In the nursery, seedlings always ceased visible top growth by the middle of October and visible root growth by late November *(fig. 3)*. The first traces of renewed root growth appeared in late February, and roots were elongating on every seedling of every source by mid-March. Bud swell consistently began in late March, after new root growth was extensive on all seedlings. The period of natural seedling dormancy generally coincided with the time when soil temperature was below 10°C (50°F). Although the winter temperature and rainfall regimes varied from year to year, they were typical of the Fruit Ridge locality.

### Root Growth Capacity (RGC)

The seed source and the nursery lifting date always affected the amount of root growth on seedlings planted in the standard environment *(table 3)*. The seed source differences in root growth capacity were large and significant in every winter season.

The seasonal patterns of RGC in the first seedling crop *(table 3A)*, representing sources from five climatic regions *(table 1)*, illustrate the range of interaction between seed source and the Fruit Ridge environment:

- Beginning November 1, after growth had ceased in the nursery, RGC was already at or near peak level in Wyoming and Arizona ponderosa pine, and in Jeffrey pine. By comparison, RGC was low to very low in California ponderosa pine.

- Between November 1 and 27, RGC in Wyoming ponderosa pine decreased by more than 60 percent and that of Jeffrey pine by more than 30 percent. RGC in Arizona ponderosa pine increased 20 percent, while RGC in the California sources increased twofold (P Eld 5500), sixfold (P SCru 800), and tenfold (P Eld 500).

- To December 21, RGC continued to increase only in P Eld 5500, seemingly decreased in the P Eld 500 and Arizona sources, and held constant in P SCru 800, Wyoming ponderosa pine, and Jeffrey pine.

- To January 24, RGC peaked a second time in Wyoming ponderosa pine and in Jeffrey pine, finally peaked in P Eld 5500 and P SCru 800, and returned to peak level in P Eld 500 and Arizona ponderosa pine.

- To March 13, RGC decreased to a moderate or low level in every source. This was two weeks after root growth began in the nursery and two weeks before bud swell *(fig. 3)*. In P SCru 800, a significant increase in the rate of root elongation partly compensated for a large decrease in the number of roots elongating, a result detected in no other source.

The apparent December depression of RGC in Arizona ponderosa pine, P Eld 500, and P SCru 800, probably reflected root damage caused by lifting the seedlings when the nursery soil was too wet. Rainfall totalled 3.4 inches (8.6 cm) for the 3 days before lifting *(fig. 3)*, and soil water contents were still at saturation. The consequent damage to small roots was evident in 17 to 27 percent decreases in the number of roots that elongated, compared to the late-November test. Thereafter, if rain was either falling or predicted, the selected block was covered with a transparent shelter for 3 days before lifting (the time the nursery soil takes to drain to field capacity at the 8-inch [20-cm] depth). The RGC of Arizona ponderosa pine showed no trace of a depression in the following winter, so values for the sources noted were adjusted upward accordingly.

Unusually intense cold did not explain the depression. In the period December 6 to 19, when air temperature was below 0°C (32°F) for 80 hours and hit a record −10°C (14°F), the seedlings were insulated under snow and soil temperature ranged from 3° to 7°C (38° to 45°F), values commonly recorded throughout the winter season. Further, seedlings lifted in January—when RGC was high and soil water content was no problem—had been fully exposed during equally cold and colder periods *(fig. 3)*.

## Seasonal Patterns of RGC

As described in an earlier paper (Jenkinson 1976), four distinct types of inherent seasonal pattern of root growth capacity were found in ponderosa pine: fall-peak, winter-peak, plateau, and bimodal. Depending on the seed source *(fig. 1, table 1)*, RGC peaked in the fall only, in midwinter only, continuously from late fall through winter, or in fall and again in winter *(table 3)*. Every pattern type occurred in ponderosa pine from both outside and inside California *(fig. 4, 5)*, and two types occurred in Jeffrey pine *(fig. 5)*.

Table 3—*Seedling growth capacities for 27 sources of western yellow pines raised in a nursery in the western Sierra Nevada*

| Seed source[1] | Growth capacity by nursery lifting date and cumulative cold exposure (hours below 10° and 5°C) | | | | | |
|---|---|---|---|---|---|---|
| A. 1972-73 winter season | Nov 1 (168, 2) | Nov 27 (648, 48) | Dec 21 (1148, 360) | Jan 24 (1864, 720) | Mar 13 (2824, 962) | |
| | Root growth capacity, *cm/seedling*[2] | | | | | |
| P AR-Coco 7000[3] | 82 b | 107 b | 73 c | 98 c | 55 ab | |
| P WY-Lar 7700 | 74 bc | 23 c | 22 d | 54 c | 25 b | |
| P SCru 800 | 9 d | 100 b | 88 abc | 215 a | 76 a | |
| P Eld 500 | 27 cd | 168 a | 122 a | 171 ab | 51 ab | |
| P Eld 5500 | 46 bcd | 88 b | 110 ab | 160 b | 59 ab | |
| J Eld 6400 | 137 a | 92 b | 86 bc | 163 b | 92 a | |
| | Top growth capacity, *index and range*[4,5] | | | | | |
| P AR-Coco 7000[3] | 1 | 1 | 2.2 (1-4) | 4.9 (3-5) | 5 | |
| P WY-Lar 7700 | 1 | 1 | 2.3 (1-4) | 4.7 (2-5) | 5 | |
| P SCru 800 | 1 | 1.1 (1-2) | 2 (1-3) | 3.6 (1-5) | 4.5 (4-5) | |
| P Eld 500 | 1 | 1.3 (1-2) | 1.8 (1-3) | 3 (1-5) | 4.3 (4-5) | |
| P Eld 5500 | 1 | 1 | 1.8 (1-3) | 3.8 (1-5) | 4.2 (4-5) | |
| J Eld 6400 | 1 | 1 | 1 | 2.8 (1-5) | 4.7 (1-5) | |
| B. 1973-74 winter season | Oct 17 (0, 0) | Nov 14 (240, 22) | Dec 6 (744, 310) | Jan 21 (1680, 670) | Feb 26 (2394, 984) | Mar 26 (2858, 1164) |
| | Root growth capacity, *cm/seedling*[2] | | | | | |
| P AR-Coco 7000[3] | 20 b | 75 a | 75 a | 73 cd | 30 cd | 14 a |
| P NE-Whi 7500 | 23 b | 57 ab | 47 b | 37 e | 27 d | 3 b |
| P OR-Kla 4300 | 40 a | 70 a | 80 a | 123 a | 91 ab | 6 b |
| P Plu 5000 | 7 c | 56 ab | 84 a | 113 ab | 113 a | 15 a |
| W NE-Wash 8000 | 46 a | 51 b | 36 b | 80 bcd | 82 b | 7 b |
| J Eld 8200 | 27 b | 52 b | 35 b | 94 abc | 52 c | 15 a |
| P Eld 6300 | 2 c | 76 a | 79 a | 86 bcd | 95 ab | 7 b |
| P Eld 1900[3] | 3 c | 49 b | 82 a | 57 de | 51 c | 7 b |
| | Top growth capacity, *index and range*[4,5] | | | | | |
| P AR-Coco 7000[3] | 1 | 1 | 1.6 (1-4) | 4.4 (4-5) | 4.4 (4-5) | 5 |
| P NE-Whi 7500 | 1 | 1 | 1.6 (1-4) | 4.4 (4-5) | 4.4 (4-5) | 4.9 (4-5) |
| P OR-Kla 4300 | 1 | 1 | 1.1 (1-2) | 4.6 (2-5) | 4.9 (4-5) | 5 |
| P Plu 5000 | 1 | 1 | 1.3 (1-2) | 4.2 (3-5) | 4.9 (4-5) | 5 |
| W NE-Wash 8000 | 1 | 1 | 1 | 4.7 (1-5) | 4.9 (3-5) | 5 (4-5) |
| J Eld 8200 | 1 | 1 | 1 | 3.1 (1-5) | 3.5 (2-5) | 4.9 (4-5) |
| P Eld 6300 | 1 | 1 | 1.3 (1-2) | 4.2 (2-5) | 4.9 (4-5) | 5 |
| P Eld 1900[3] | 3 | 1 | 1.2 (1-2) | 3.8 (2-5) | 4.4 (4-5) | 5 (4-5) |

Table 3—*(Continued)*

| Seed source[1] | Growth capacity by nursery lifting date and cumulative cold exposure (hours below 10° and 5°C) | | | | |
|---|---|---|---|---|---|
| C. 1974-75 winter season | Oct 31 (81, 2) | Dec 4 (593, 39) | Jan 21 (1492, 348) | Feb 19 (2085, 659) | Mar 19 (2587, 827) |
| | Root growth capacity, *cm/seedling*[2] | | | | |
| P Eld 4000[3] | 55 a | 97 a | 172 a | 108 ab | 55 ab |
| P Eld 1900[3] | 35 b | 95 a | 147 a | 97 b | 48 bc |
| P Eld 1900† | 54 a | 82 a | 160 a | 79 bc | 43 bc |
| P Ama 750 | 32 b | 47 bc | 134 ab | 67 c | 28 c |
| P Pla 3800† | 65 a | 69 b | 149 a | 109 ab | 56 ab |
| J Pla 3800† | 31 b | 39 c | 118 b | 70 c | 39 c |
| P Sha 4840 | 56 a | 84 a | 171 a | 130 a | 68 a |
| | Top growth capacity, *index and range*[4,5] | | | | |
| P Eld 4000[3] | 1 | 1 | 3.8 (2-5) | 4.3 (4-5) | 4.6 (4-5) |
| P Eld 1900[3] | 1 | 1 | 4.3 (3-5) | 4.4 (4-5) | 4.7 (4-5) |
| P Eld 1900† | 1 | 1 | 3.8 (1-5) | 4.2 (4-5) | 4.4 (4-5) |
| P Ama 750 | 1 | 1 | 3.8 (1-5) | 4.4 (4-5) | 4.7 (4-5) |
| P Pla 3800† | 1 | 1 | 3.8 (1-5) | 4.1 (4-5) | 4.6 (4-5) |
| J Pla 3800† | 1 | 1 | 1.2 (1-5) | 3.0 (1-5) | 3.4 (1-4) |
| P Sha 4840 | 1 | 1 | 3.9 (1-5) | 4.4 (1-5) | 4.8 (1-5) |

| D. 1975-76 winter season | Oct 24 (0, 0) | Nov 13 (486, 24) | Dec 8 (901, 158) | Jan 6 (1468, 390) | Feb 3 (1815, 493) | Mar 2 (2355, 675) |
|---|---|---|---|---|---|---|
| | Root growth capacity, *cm/seedling*[2] | | | | | |
| P Eld 4000[3] | 3 | 69 a | 129 ab | 122 a | 162 a | 125 a |
| P Los 6700 | 1 | 63 a | 100 bc | 91 a | 157 a | 108 a |
| P Los 6200 | 1 | 73 a | 124 b | 90 a | 162 a | 112 a |
| P Los 5350 | 6 | 51 ab | 137 ab | 58 b | 145 a | 71 b |
| J Los 5150 | 1 | 33 b | 61 c | 13 d | 44 bc | 30 c |
| P SBer 5370 | 4 | 70 a | 157 a | 97 a | 150 a | 105 a |
| J SBer 6900 | 8 | 19 b | 76 c | 44 bc | 66 b | 49 b |
| J SBer 5660 | 3 | 27 b | 57 c | 30 c | 32 c | 52 b |
| J SDie 5320 | 2 | 23 b | 62 c | 27 cd | 70 b | 44 bc |
| | Top growth capacity, *index and range*[4,5] | | | | | |
| P Eld 4000[3] | 1 | 1 | 1.3 (1-2) | 2.5 (1-3) | 3.8 (3-5) | 4.6 (4-5) |
| P Los 6700 | 1 | 1 | 1.2 (1-2) | 1.5 (1-3) | 3.3 (3-4) | 4.5 (3-5) |
| P Los 6200 | 1 | 1 | 1.2 (1-2) | 1.6 (1-3) | 3.1 (2-4) | 4.4 (3-5) |
| P Los 5350 | 1 | 1 | 1.3 (1-2) | 1.6 (1-2) | 2.5 (1-4) | 4.6 (4-5) |
| J Los 5150 | 1 | 1 | 1 | 1 | 1.7 (1-4) | 2.6 (1-4) |
| P SBer 5370 | 1 | 1 | 1 | 1.9 (1-3) | 3.9 (2-5) | 4.8 (4-5) |
| J SBer 6900 | 1 | 1 | 1 | 1 | 2.0 (1-4) | 3.1 (2-5) |
| J SBer 5660 | 1 | 1 | 1 | 1.1 (1-2) | 1.4 (1-2) | 3.1 (2-5) |
| J SDie 5320 | 1 | 1 | 1 | 1.3 (1-2) | 2.1 (1-4) | 3.1 (2-5) |

[1]For source designation, see *figure 1;* † indicates source is native on infertile, ultramafic soil.
[2]Within columns, means followed by unlike letters differ significantly (p = 0.05).
[3]Source tested in consecutive years.
[4]An index value of 1 = top dormant, 2 = fascicle buds swelling, 3 = 2 and color change in apical centimeter of stem, 4 = 2 and leader elongating, 5 = leader and needles elongating.
[5]In the March tests, the zone of leader elongation, by year and source, reached these lengths (mm):
1973. 56, 74, 70, 50, 53, and 53
1974. 92, 75, 26, 68, 47, 52, 69, and 79
1975. 51, 65, 62, 65, 54, 22, and 54
1976. 55, 46, 56, 58, 21, 67, 24, 31, and 22

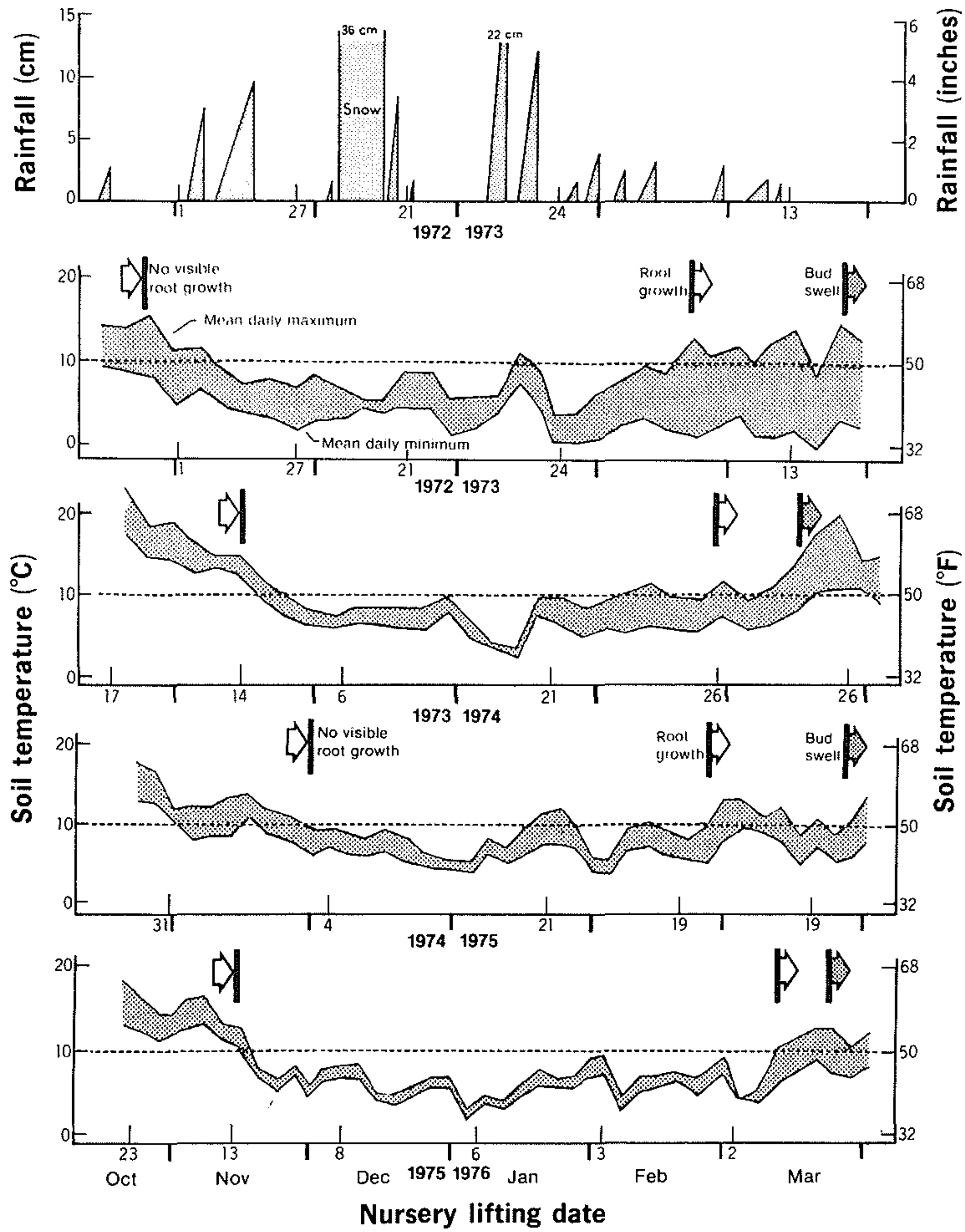



**Figure 3**—Under rainfall and temperature regimes typical of the winter season on Fruit Ridge, seedlings of western yellow pines in the nursery cease root growth in fall when soil cools below 10° C, resume it in spring when soil warms above 10° C, and begin top growth 2 to 5 weeks after root growth. Through each winter season, seedlings in the nursery beds were periodically sampled for tests of growth capacity.

## Fall-peak

A unimodal pattern with a fall peak characterizes ponderosa pine from the Basin and Range region (P NE-Whi 7500). In the same winter season, a similar fall-peak pattern appeared in ponderosa pine from the pine phase of mixed conifer forest in the western Sierra Nevada (P Eld 1900). In the next season, however, five of those families and five others from a nearby stand on ultramafic soil (P Eld 1900†) produced patterns with a midwinter peak, suggesting either large variability among the seed parents or yearly differences in nursery climate.

## Winter-peak

Unimodal patterns with a midwinter peak characterize ponderosa pine from east of the Cascade Range (P OR-Kla 4300, P Sha 4840), from coastal California (P SCru 800), and from the western Sierra Nevada. In the latter region, sources from granitic soils in the mixed phase of mixed conifer forest (P Eld 4000, 5500) produced patterns conforming to earlier experience (Stone and Schubert 1959). Ponderosa pine from P Eld 4000 repeated this winter-peak pattern in consecutive years, and similar patterns appeared in sundry other sources from the western Sierra, including ponderosa and Jeffrey pines from ultramafic soil (P, J Pla 3800†) and ponderosa pine from a foothill woodland (P Ama 750).

## Plateau

A plateau type of pattern characterizes ponderosa pine from the center of the most extensive forest on the Colorado Plateau. Root growth capacity in Arizona ponderosa pine (P AR-Coco 7000), evaluated in consecutive years, was consistently at peak levels from October to February. Plateau patterns also appeared in California ponderosa pine from the western Sierra foothills (P Eld 500) and from Lake Tahoe Basin in the eastern Sierra Nevada (P Eld 6300).

## Bimodal

Bimodal patterns typify ponderosa pine from east of the Continental Divide and both Washoe pine and Jeffrey pine from east of the Sierra crest. The patterns for Wyoming ponderosa pine (P WY-Lar 7700) and Tahoe Basin Jeffrey pine (J Eld 6400) were clearly bimodal because two lifting

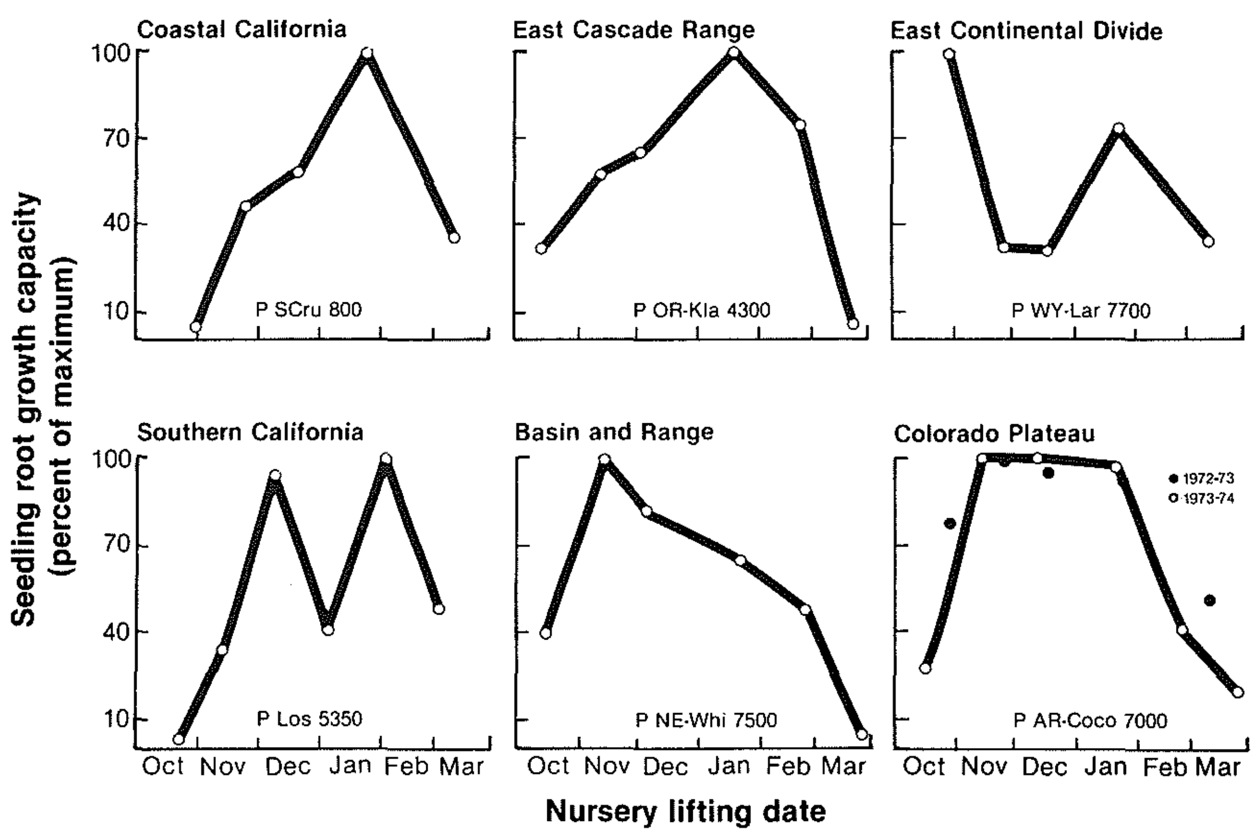



**Figure 4**—In ponderosa pine from diverse climatic regions, changes in seedling root growth capacity define four distinct types of seasonal pattern: winter-peak (northern California and Oregon), bimodal (Wyoming and southern California), fall-peak (Nevada), and plateau (Arizona).

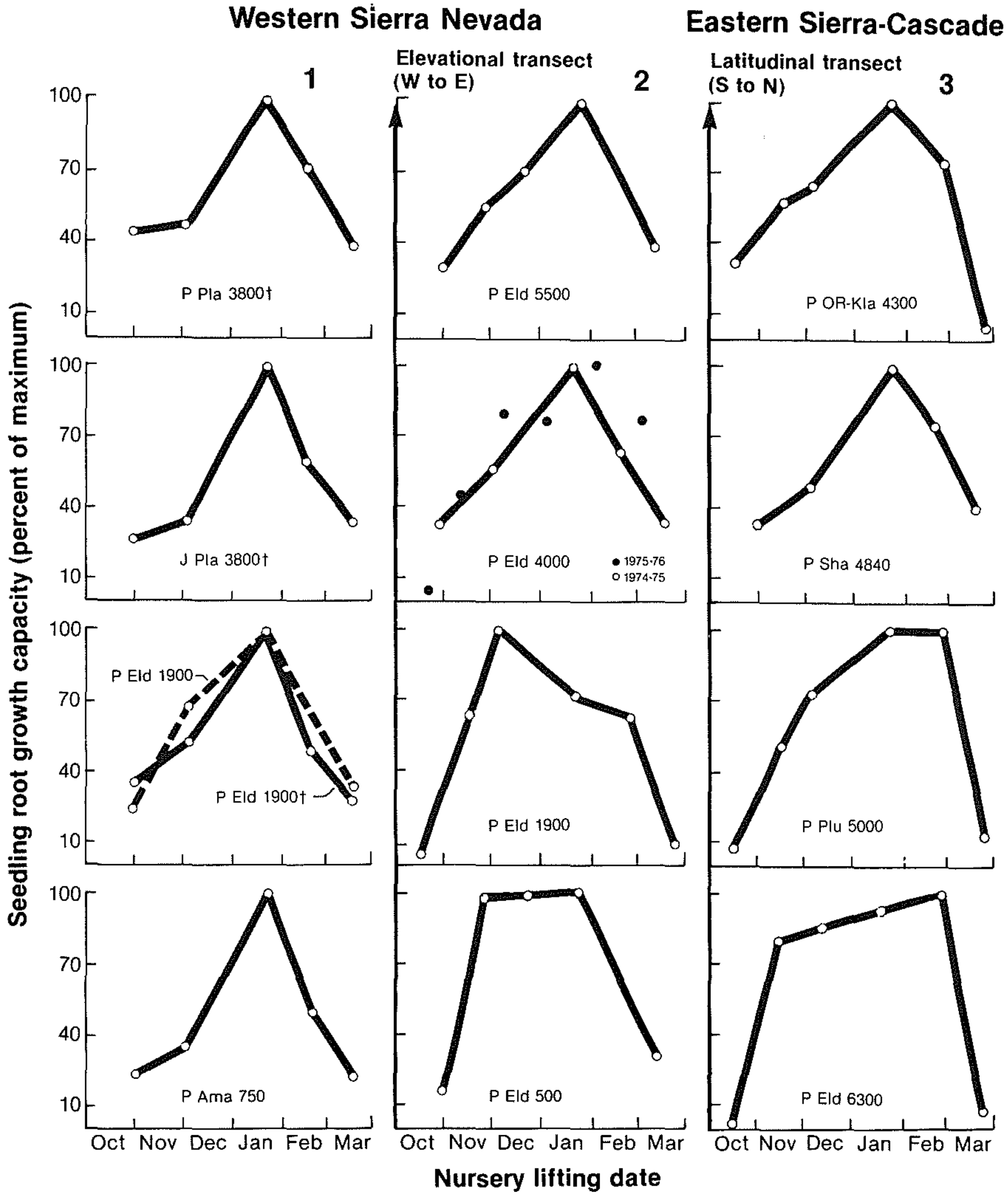
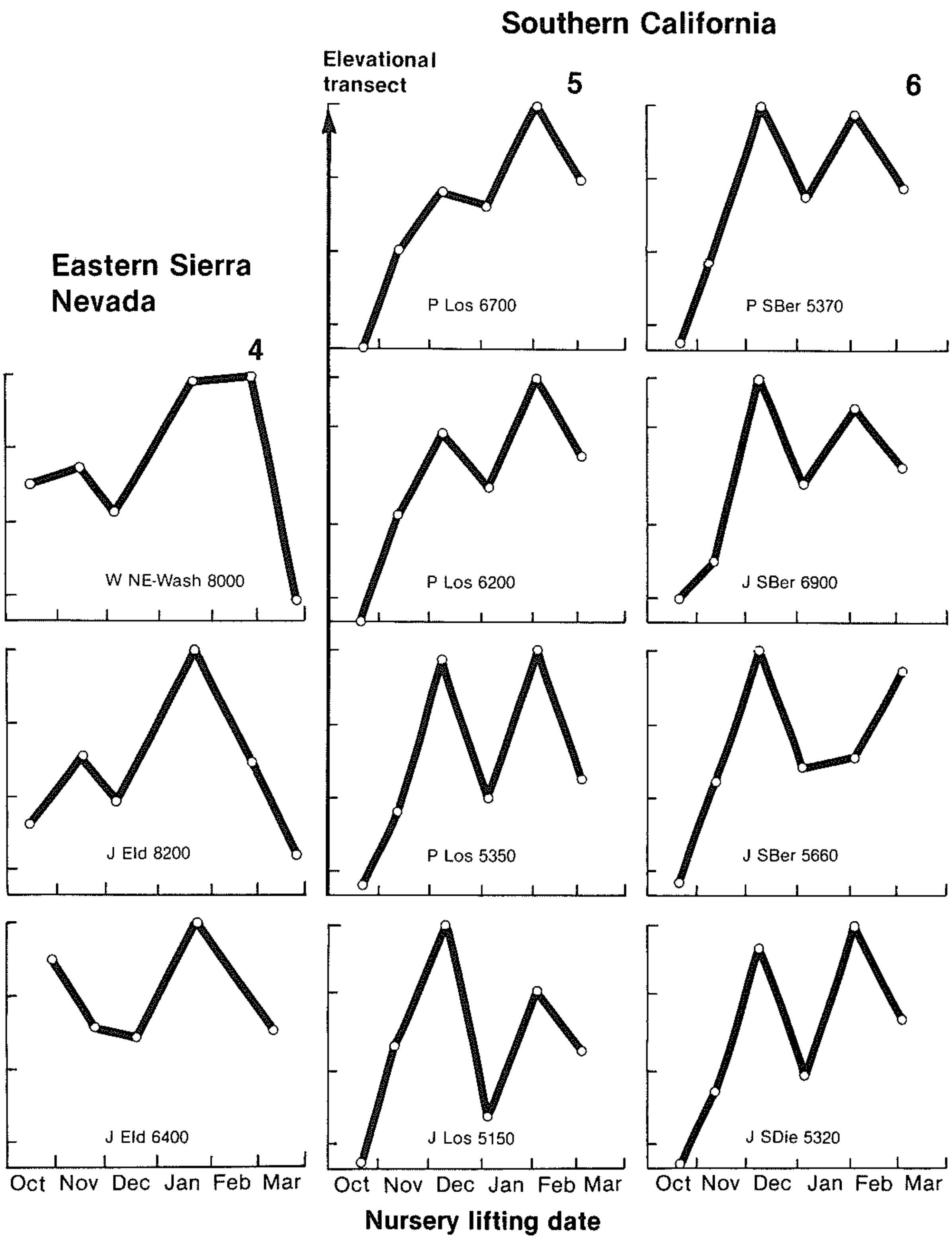



**Figure 5**—In California ponderosa and Jeffrey pines, the seasonal pattern of seedling root growth capacity varies with climatic region, latitude *(panel 3)*, and elevation of the parent stand *(panels 2, 5)*. In Washoe pine (W NE-Wash 8000), the pattern resembles that of the local region Jeffrey pine (J Eld 8200) in October-December and ponderosa pine (P Plu 5000, P Eld 6300) in January-March.


Southern California
Elevational transect
5
6
Eastern Sierra Nevada
4
P Los 6700
P SBer 5370
W NE-Wash 8000
P Los 6200
J SBer 6900
J Eld 8200
P Los 5350
J SBer 5660
J Eld 6400
J Los 5150
J SDie 5320
Oct Nov Dec Jan Feb Mar
Oct Nov Dec Jan Feb Mar
Oct Nov Dec Jan Feb Mar
Nursery lifting date

dates defined the December low between peaks.

Bimodal patterns also characterize both ponderosa pine and Jeffrey pine from southern California, but for this region the low between peaks appeared in January. In Jeffrey pine from the Santa Ana River watershed (J SBer 5660), two lifting dates defined the low between peaks, and the second peak was later than in other sources. In ponderosa pine from the San Gabriel Mountains, the pattern varied from strongly bimodal (P Los 5350) to obscurely so (P Los 6700), suggesting a shift toward a winter-peak pattern with increase in elevation of the parent stand *(fig. 5, panel 5).*

## Environmental Gradients

For seed sources in the same climatic region, shifts in pattern type apparently reflect gradients in the regional temperature and moisture regime. Patterns from the transect of ponderosa pine within the American River drainage of the western Sierra Nevada suggest an elevational gradient of root growth capacity *(fig. 5, panel 2).* In sources from 500 to 5500 ft (P Eld 500, 1900, 4000, 5500), the time needed to reach peak RGC increased with increasing elevation of the parent stand. Simultaneously, the duration of peak level decreased.

Contrasting patterns typify sources from opposite sides of the Sierra Nevada crest, the topographic barrier separating two major climatic regions. In ponderosa pine from similar granitic soils and south slopes, and from the same mixed conifer association except for Douglas-fir, the pattern type changed from one of slow increase and a midwinter peak of short duration (P Eld 5500) to one of rapid increase and a peak level spanning more than 3 months (P Eld 6300). In Jeffrey pine, the patterns were bimodal types in sources from east of the crest (J Eld 6400, 8200) and a winter-peak type from the western slope (J Pla 3800†).

Patterns from the transect of ponderosa pine east of the Sierra-Cascade crest suggest a latitudinal gradient of root growth capacity *(fig. 5, panel 3).* In sources from the west shore of Lake Tahoe (P Eld 6300), the northern Sierra Nevada (P Plu 5000), northeastern California (P Sha 4840) and southern Oregon (P OR-Kla 4300), the time needed to reach peak RGC increased with increasing latitude of the parent stand, and the duration of peak level decreased.

Apart from the elevational and latitudinal shifts, variation in the seasonal pattern is not readily related to climate at the seed source. The same pattern type was commonly associated with diverse native climates: every type appeared in at least two climatic regions, and three appeared in three regions *(fig. 4, 5).*

## Top Growth Capacity

Unlike root growth capacity, top growth capacity in every source displayed a sigmoid seasonal pattern *(fig. 6).* The pattern is like that of leader elongation on western white pine seedlings (*P. monticola* Dougl.) chilled at 5°C (41°F) for periods varying from 8 to 20 weeks (Steinhoff and Hoff 1972), and of bud burst and shoot growth on Douglas-fir periodically sampled in a nursery and tested in standard environments through a winter season (Lavender and Hermann 1970).

The amount of natural cold exposure that dormant seedlings needed to break buds and flush rapidly was least in Washoe pine and ponderosa pine from continental climates, and greatest in Jeffrey pine. In California ponderosa pine and Jeffrey pine, the exposure required apparently was least in sources from the eastern Sierra-Cascade region, intermediate in sources from the western Sierra Nevada and coastal California, and greatest in sources from southern California *(table 3, fig. 6).*

Differences in the development of top growth capacity during a single winter season *(table 3B),* in yellow pines from four climatic regions *(table 1),* illustrate the range of interaction between seed source and the Fruit Ridge climate:

- In October, before air temperature dipped below 10°C (50°F), ponderosa pines from continental climates, Washoe pine, and Jeffrey pine remained dormant in the standard environment. In contrast, ponderosa pine from the western Sierra Nevada (P Eld 1900) resumed leader growth under the 16-hour photoperiod.

- In November, after 200 hours of cold exposure, every source remained dormant.

- In early December, after 700 hours of cold, the ponderosa pines produced small amounts of top growth, with Arizona and Nevada sources showing the most. There was no trace of top growth in Washoe pine and Jeffrey pine.

- In January, after 1600 hours of cold, top growth was greatest on Washoe pine and Oregon ponderosa pine, with both leaders and needle fascicles elongating rapidly. Leader growth was clearly greater in Arizona, Nevada, and California ponderosa pines from east of the Sierra Nevada crest (P Plu 5000, P Eld 6300) than in ponderosa pine from the western Sierra (P Eld 1900). Top growth was least in Jeffrey pine, with terminal and fascicle buds swelling but not elongating.

- In February, after 2400 hours of cold, top growth exceeded that for January in every source except Arizona and Nevada ponderosa pines, which remained the same. Top growth was greatest in Washoe pine and ponderosa pine from the eastern

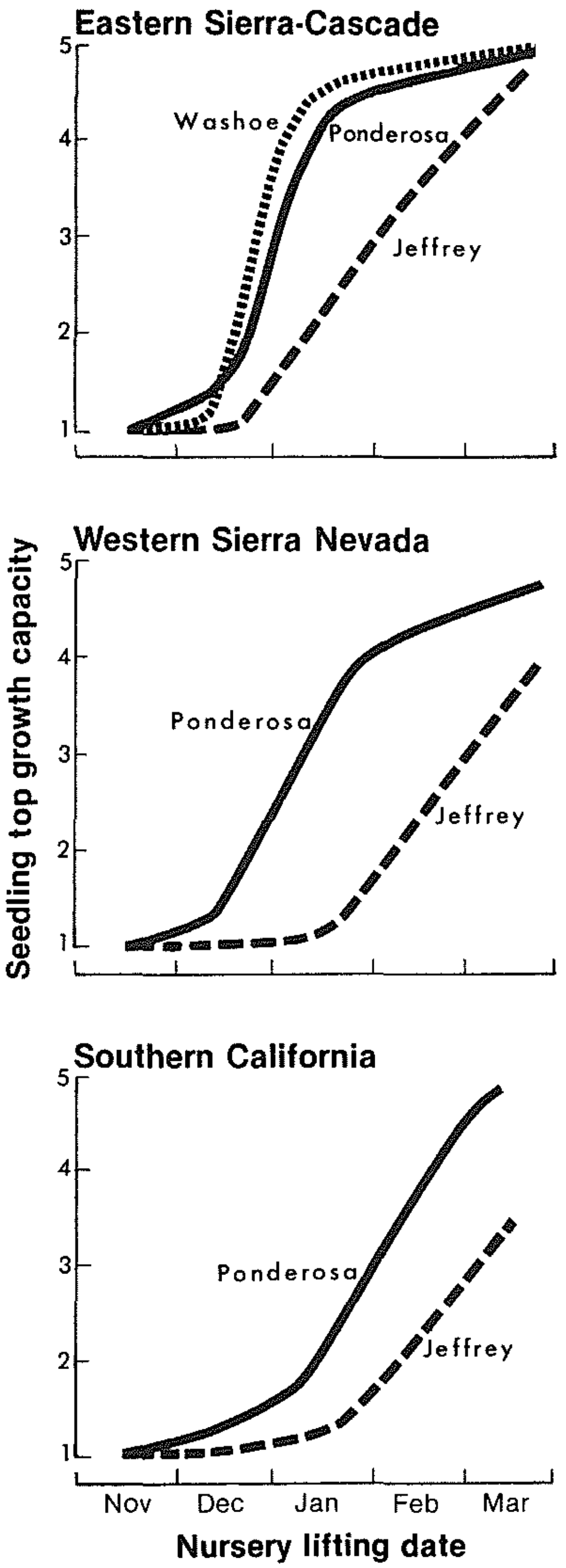



**Figure 6**—Seedlings of ponderosa and Washoe pines develop top growth capacity earlier and faster than Jeffrey pine, and sources from the eastern Sierra-Cascade region develop it sooner than sources from southern California. A value of 1 on the scale indicates dormancy; 5 indicates rapid elongation of leader and needles.

Sierra-Cascade region (P OR-Kla 4300, P Plu 5000, P Eld 6300), and least in Jeffrey pine.

• In late March, needle elongation was exceptional in every source because top growth had begun in the nursery. The top growth index already was 3.9 for Washoe pine, 3.5 to 3.9 for ponderosa pine, and 2.4 for Jeffrey pine.

## Field Survival

Large differences in seedling survival were associated with planting time, seed source, and site environment.

### Planting Time Study

In 1973, field survival was 20 to 78 percent greater for the seedlings planted in March, even though root growth capacity was 2 to 3 times higher in the seedlings planted in January *(table 4)*. Survival was also greater for the California than for the Wyoming and Arizona sources, averaging 79 against 27 and 37 percent in the January planting, and 98 against 46 and 66 percent in the March planting.

Most seedlings in both plantings had elongated leaders by early May. By June, however, some were curtailing needle growth, suggesting high plant water stress. In July, mortality appeared in every source in the January planting, and in the Wyoming source in the March planting. Mortality continued until October, when rains ended the summer drought.

In 1974, planting time had no effect and survivals were uniformly high *(table 4)*. Survivals ranged from 88 to 100 percent in the February planting, and from 92 to 100 percent in the March planting, even though top growth was well underway when the March seedlings were lifted. Heavy rains fell in April, and in early July over 3 inches (8 cm) recharged the soil profile and eliminated lethal plant water stress for the rest of the summer season.

### Site Environment Study

In November, field survivals of all sources ranged from 85 to 95 percent at Mt. Danaher, 94 to 99 percent at Angora Creek, and 82 to 91 percent at Lincoln Hill *(table 5)*. Differences between sources were not significant on any of those three sites. Gophers caused 80 percent of the mortality at Mt. Danaher, and 87 percent at Lincoln Hill. Mortality was light and random in the second year, and did not alter the first year's results.

At Salmon Falls, survivals were 87 to 93 percent in June, but ranged from 39 to 59 percent in late August. Severe grass competition for soil water accounted for 91 percent of the midsummer mortality. Survivals of ponderosa pine from the western

Table 4—*Root growth capacity (RGC) and field survival of western yellow pines planted in winter and in spring, below snow line in the western Sierra Nevada (planting time study)*[1]

| Test year and seed source[2] | Winter planting | | Spring planting | |
|---|---|---|---|---|
| | RGC when planted | Field survival | RGC when planted | Field survival |
| | *Cm/seedling* | *Percent* | *Cm/seedling* | *Percent* |
| *1973* | | | | |
| P AR-Coco 7000[3] | 98 | 37 | 55 | 66 |
| P WY-Lar 7700 | 54 | 27 | 25 | 46 |
| P SCru 800 | 215 | 80 | 76 | 96 |
| P Eld 500 | 171 | 81 | 51 | 98 |
| P Eld 5500 | 160 | 79 | 59 | 98 |
| J Eld 6400 | 163 | 75 | 92 | 98 |
| *1974* | | | | |
| P AR-Coco 7000[3] | 30 | 96 | 14 | 98 |
| P NE-Whi 7500 | 26 | 88 | 3 | 96 |
| P OR-Kla 4300 | 91 | 94 | 6 | 98 |
| P Plu 5000 | 113 | 98 | 15 | 100 |
| W NE-Wash 8000 | 81 | 96 | 7 | 96 |
| J Eld 8200 | 52 | 100 | 15 | 100 |
| P Eld 6300 | 94 | 98 | 7 | 98 |
| P Eld 1900[4] | 51 | 100 | 7 | 92 |

[1]Seedlings were transplanted from Fruit Ridge to Garden Valley *(table 2)* on January 23 and March 14, 1973; February 27 and March 28, 1974.
[2]For source designation, see *figure 1.*
[3]Source tested in consecutive years.
[4]Source native to Garden Valley locality.

Table 5—*Field survival of ponderosa and Jeffrey pines planted west and east of the Sierra Nevada crest (site environment study)*[1]

| Seed source[2] | Seedling survival | | | | | |
|---|---|---|---|---|---|---|
| | Western Sierra Nevada | | | | | Eastern Sierra Nevada |
| | Salmon Falls | | | | | |
| | *Jun 13, 1973* | *Aug 23, 1973* | *Mar 6, 1974* | Mt. Danaher *Nov 1973* | Lincoln Hill *Nov 1974* | Angora Creek *Nov 1973* |
| | *Percent* | | | | | |
| Western Sierra | | | | | | |
| P Eld 500[3,4] | 92.5 | 57.6 | 46.7 | 88.7 | 84.1 | 97.5 |
| P Eld 1900[3] | — | — | — | — | 82.5 | — |
| P Eld 4000 | 93.6 | 57.6 | 55.0 | 91.6 | 88.1 | 99.4 |
| P Pla 3800† | 91.6 | 59.4 | 55.4 | 93.2 | 84.4 | 97.8 |
| J Pla 3800† | 88.5 | 47.1 | 43.5 | 92.7 | 90.3 | 94.7 |
| Eastern Sierra[3] | | | | | | |
| P Eld 6300 | 89.6 | 40.8 | 39.2 | 85.6 | 90.9 | 97.8 |
| J Eld 6400 | 93.6 | 43.3 | 37.7 | 95.3 | 88.1 | 97.8 |
| J Eld 8200 | 87.2 | 39.1 | 31.0 | 87.9 | 88.7 | 95.2 |

[1]Seedlings lifted in late winter and held in cold storage were outplanted in spring, 1973 (Salmon Falls, March 5-9; Mt. Danaher, March 29-April 2; and Angora Creek, May 17-19) and 1974 (Lincoln Hill, April 17-19).
[2]For source designation, see *figure 1;* † indicates source is native on infertile, ultramafic soil.
[3]Source tested at Garden Valley *(table 4).*
[4]Source native to Salmon Falls locality.

Sierra Nevada (P Eld 4000, P Pla 3800†, and P Eld 500—the "home team") were significantly higher than those of ponderosa pine (P Eld 6300) and Jeffrey pine (J Eld 6400, 8200) from east of the Sierra crest, that is, 57 to 59 percent as against 39 to 43 percent. Midsummer survival of Jeffrey pine from the western Sierra (J Pla 3800†) was intermediate at 47 percent. In the following year, survivals still ranged from 31 to 55 percent, with no change in rank for any source.

## DISCUSSION

Seedlings of western yellow pines vary widely in root growth capacity. For most seed sources, this latent capacity changes continuously through the fall and winter, even while the seedlings are fully dormant and show no visible growth in the nursery bed. The inherent seasonal pattern of RGC is revealed when the seedlings are periodically sampled and tested for growth in a standard environment. For the 27 sources investigated *(fig. 1)*, specific interactions with the nursery climate on Fruit Ridge generate four distinct types of seasonal pattern in ponderosa pine and two distinct types in Jeffrey pine *(fig. 4, 5)*.

In the Fruit Ridge climate, seedlings consistently develop a root growth capacity that ensures high survival in the field. As demonstrated in the elevational array of test plantings across the central Sierra Nevada *(tables 4, 5)*, high survival is routine if dormant seedlings with just moderate capacity are planted shortly before or during the local onset of spring conditions. *In essence, the key to plantation establishment for a particular seed source is knowing when to lift the seedlings in the nursery and when to plant them in the field.*

### *Seed Source, Nursery Environment, and RGC*

The seed source and the climatic conditioning that seedlings receive in the nursery determine the ability of lifted seedlings to produce new root growth. With identical conditioning, the typical sources of western yellow pines increase in root growth capacity at very different times and at very different rates.

Most of the California sources of ponderosa pine apparently require large amounts of cold exposure to trigger increase in RGC, but the Wyoming, Arizona, Nevada and Oregon sources, along with Washoe pine and Jeffrey pine from east of the Sierra Nevada crest, clearly do not *(table 3A, B)*. With little or no cold exposure, RGC in Washoe pine and Jeffrey pine (J Eld 8200) from the Carson Range was moderately high and 4 to 20 times greater than RGC in ponderosa pine from either the eastern or western Sierra Nevada (P Plu 5000, P Eld 6300, P Eld 1900). After less than 170 hours of exposure, RGC in Tahoe Basin Jeffrey pine (J Eld 6400) peaked and was 3 to 15 times greater than RGC in ponderosa pine from the western Sierra (P Eld 5500, 500) and coastal California (P SCru 800). In a controlled-environment study of ponderosa pine from the western Sierra, RGC increased rapidly and in direct proportion to cold exposure, but only after 540 hours—60 nights—at 6°C (43°F, Krugman and Stone 1966).

Annual evaluations of ponderosa pine in the Ben Lomond Nursery, in the Santa Cruz Mountains of coastal California, showed that RGC peaked 5 to 9 weeks earlier in the colder winter seasons, suggesting that more intense cold exposure speeds the development of RGC (Stone and Jenkinson 1971). And so it may. However, those evaluations necessarily covered a single source from coastal California in the warm winter, and a different source from southern California in each of the cold winters.

Present evidence shows that the seed source exerts major control over the time that RGC takes to peak. For example, in the same winter season, RGC in a foothill source from the western Sierra Nevada (P Eld 500) peaked in less than 1 month, while RGC in typical sources from the higher western Sierra (P Eld 5500) and coastal California (P SCru 800) peaked in 3 months *(table 3A)*. The RGC in one source from the eastern Sierra (P Eld 6300) also peaked in 1 month, while RGC in another (P Plu 5000) took 3 months *(table 3B)*. Finally, RGC in ponderosa and Jeffrey pines from southern California (P Los 5350, P SBer 5370, J Los 5150, J SBer 5660, J SDie 5320) reached the first peak within 2 months, while RGC in ponderosa and Jeffrey pines from the western Sierra (P Eld 4000; P,J Pla 3800†) peaked after 3 months *(table 3C, D)*. Equally large differences are also obvious among ponderosa pines from the Western United States *(fig. 4)*.

Such frequent differences between sources in both onset and rate of increase in RGC clearly restrict application of the simple cold-exposure mechanism hypothesized for ponderosa pine with a winter-peak pattern (Stone and Jenkinson 1970). In any source with a fall-peak or bimodal pattern, changes in RGC are difficult to explain solely in terms of seedling response to cold in the nursery. Most of these sources are typified by short native growing seasons, the result of prolonged summer droughts in southern California and of long, subfreezing winters in the continental regions.

In the continental sources (P WY-Lar 7700, P AR-Coco 7000, P NE-Whi 7500, P OR-Kla 4300, W NE-Wash 8000, P Eld 6300; J Eld 6400, 8200), both top dormancy and high RGC develop in the fall, before the seedlings experience natural cold exposure. This early condition is probably induced by the seasonal decrease in day length, but might also be part of a genetically fixed pattern of annual growth. In ponderosa pine from latitudes 43°N in Nebraska and 33°N in New Mexico, both shoot elongation and weight increase depend on photoperiod (Tinus 1977). In Douglas-fir from latitudes 48°N in Montana and 33°N in New Mexico, seedlings grown under an 18-hour photoperiod enter dormancy independently of the soil and air temperature regime (Lavender and Overton 1972). Whether induced by decreasing photoperiod or inherent pattern, growth cessation and dormancy apparently channel current photosynthate into carbohydrate reserves for future growth (Kreuger and Trappe 1967, Stone and Jenkinson 1970).

In sources with a bimodal pattern, the winter lows of RGC might also be genetically fixed, or might be caused by cold exposure. If the seedlings respond to cold by shifting into deep dormancy, they could require extended time in the standard environment before root growth can commence. This hypothetical delay of growth is suggested by two physiological responses of Scots pine seedlings *(P. sylvestris L.)* hardened by winter cold and transferred to a warm environment. The photosynthesis of hardened seedlings is sharply reduced, and takes 7 to 9 days to recover to high rates (Zelawski and Kucharska 1967). Similarly, the transpiration of hardened seedlings is cut by half and takes 10 to 14 days to reach maximum rates (Christersson 1972).

On Fruit Ridge, the western yellow pines begin root growth within a week when soil at the 3-inch depth consistently warms above 10°C (50°F). In a few sources (P Plu 5000, P Eld 6300, W NE-Wash 8000), a precipitous drop in seedling root growth capacity coincides with the start of spring root growth. In other sources, however, significant declines in RGC start 4 to 15 weeks before root growth resumes. Once root growth does resume, the seedlings' translocatable reserves are rapidly spent in the nursery bed, and elongating roots invariably are damaged during lifting. The consequent losses of food reserves and root tips reduce RGC in every source.

The reduced RGC of most sources in March is also partly explained by the seedlings' rapid top growth in the standard environment. Root growth is naturally reduced once top growth is underway (Cannell and Willett 1976, Eliasson 1971, Lathrop and Mecklenburg 1971). Bud break markedly curtails translocation to elongating roots, and expanding shoots effectively compete for translocatable reserves and current photosynthate (Gordon and Larson 1968, Shiroya and others 1966, Zeimer 1971). In the January or February tests, however, root growth apparently hit peak levels regardless of the coincident top growth.

Inherent variation in the chilling required to break top dormancy had no discernible effect on field growth and survival. The chilling requirements of ponderosa and Washoe pines were essentially satisfied by January, before seedlings were lifted for outplanting. The chilling of Jeffrey pine transplanted in midwinter to Garden Valley apparently was completed on site. Abundant experience with yellow pines, Douglas-fir, and true firs grown on Fruit Ridge has shown that chilling is effectively completed in storage at 1°C (34°F), even for seedlings lifted in December, 6 to 12 weeks before natural cold exposure ensures normal spring top growth.

## *Planting Time and Field Survival*

To select planting time is to choose—consciously or not—the initial climatic environment of planted seedlings. Seedlings in the best physiological condition are endangered when outplanted far in advance of site conditions that enable them to maintain a favorable water balance and begin root growth. In cold soils, planted seedlings cannot grow roots, will undergo high water stress, and will expend stored reserves. The consequent loss of seedling root growth capacity means seedling mortality during the summer drought.

Thus, field survivals in my January and March outplantings were just the reverse of those forecast by root growth capacity *(table 4)*. The January seedlings were lifted at peak RGC, but were planted long before root growth could start. Observations of the time when root growth resumed in the nursery and of soil temperatures there *(fig. 3)* and at Garden Valley show that the planting site was too cold to support root growth until March. Apparently, the seedlings planted in January had their roots in cold soil for about 6 weeks. Seedling roots of western yellow pines elongate very slowly at 10°C (50°F),[2] if they grow at all (Stone and Schubert 1959, Stone and Norberg 1979.)

Besides preventing root growth, a cold soil will cause physiological drought in newly planted pines, even though their stomatal control of transpiration is efficient (Lopushinsky 1969, Lopushinsky and Klock 1974). Because soil temperatures below 10°C increase the viscosity of water and sharply increase

[2]Jenkinson, James L. Data filed 1973. Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

root resistance to water flow (Kaufmann 1975, 1977), the water uptake of pine is reduced 50 to 70 percent in soil at 5°C (41°F) and 85 percent in soil near freezing (Kramer 1942). This reduction in uptake typically produces large increases in plant water stress. With soil water contents near field capacity, soil temperatures below 7°C (45°F) cause daytime stress to exceed 16 bars (atm) in orange (*Citrus* spp.)—even 35 bars below 2°C (36°F), and delay recovery to predawn values until well after sunset (Elfving and others 1972). In Engelmann spruce (*Picea engelmannii* Parry), daytime stress is consistently in the 15- to 20-bar range when soil temperatures are below 7°C; below 5°C (41° to 32°F), stress increases rapidly and exceeds 15 bars even at slow rates of transpiration (Kaufmann 1975). For planted seedlings of Monterey pine (*Pinus radiata* D. Don), maintaining the soil at 5°C can hold daytime stress above 20 bars (Nambiar and others 1978). Cold soil undoubtedly affects the western yellow pines, and especially bare-root seedlings, just as it does orange and spruce.

When daytime stresses are chronically high, the planted seedlings may starve. Respiration of drought-stressed plants often exceeds their photosynthesis, resulting in net losses of reserve carbohydrates (Levitt 1972). In pine, respiration at 10 to 15 bars may be 60 percent of the rate without stress and may climb to 140 percent above 25 bars (Brix 1962). By contrast, photosynthesis plummets when daytime stress tops 5 or 10 bars, and ceases between 10 and 20 bars (Brix 1962, Cleary 1971). Any loss of reserves on the planting site probably diminishes RGC, since seedlings lifted at the peak may lose RGC even in polybags at 1°C (34°F), under zero stress and respiring at minimal rate (Stone and Jenkinson 1971).

Root growth capacity of the seedlings outplanted in March was far below that in January, but still ranged from 0.5 to 0.9 m in the California sources *(table 4)*. The soil warmed enough for rapid root growth in March, and the availability of soil water remained high through April. This favorable environment enabled adequate water uptake and immediate root elongation, thereby compensating for the lower RGC of the March seedlings. Bud swell—triggered by soil temperature (Lavender and others 1973, Paton and others 1979) and regulated by air temperature (Sorensen and Campbell 1978)—began on all seedlings in April, so top growth initially was not competing with root growth in either of the plantings.

In both plantings, Wyoming ponderosa pine had the lowest RGC and the poorest survival. But survival also reflected the degree to which sources in different climatic regions are adapted to drought. California ponderosa pine and Jeffrey pine were superior to Arizona ponderosa pine, which in turn was superior to Wyoming ponderosa pine. The California sources are adapted to summer drought, but the Arizona and Wyoming sources are not. Heavy rains are normal in July and August in central Arizona, and fall throughout the growing season in southeastern Wyoming.

In the following year, planting time had no effect on seedling survival because soil temperature immediately supported root function and growth in both plantings *(table 4)*. Further, timely spring and summer rains ensured the continued availability of water even to seedlings nearly incapable of root elongation. The heavy July rain, totally atypical of California summers, was simply "normal" for Arizona and Nevada ponderosa pines. One year later, however, those sources and Washoe pine had significant mortality and the California sources did not, a result consistent with that in the earlier test.

## Improving Plantation Establishment

California sources of ponderosa and Jeffrey pines are readily established in the field, provided that seedlings are lifted at the right time in winter, stored properly (Jenkinson 1975), planted at the right time in spring, and protected against both competing vegetation and animal damage. The same provisions ensure establishment of Douglas-fir in western Oregon and California (Jenkinson and Nelson 1978), and of true firs in the Siskiyou Mountains, Shasta Cascades and western Sierra Nevada[3] (Jenkinson 1978, Stone and Norberg 1979).

In the Fruit Ridge climate, every source of yellow pine develops a moderate or high root growth capacity sometime between November and March, when nursery soil and air temperatures prevent the growth of pine. Lifted and stored at the right time, seedlings delivered to the planting sites are fully dormant and have an RGC greater than the minimums associated with high survival in my field tests.

On every planting site, cold soil fixes the earliest date and excessive evaporative stress fixes the latest date that seedlings can be planted safely. Planted at the right time, seedlings enter the site when daily soil temperatures are warming above 5°C (41°F)—warm enough for water uptake, and will soon exceed 10°C (50°F)—warm enough for root elongation. Within this "planting window", soil water contents remain at or near field capacity. Typical spring rains on most sites will settle the soil in planting holes, sealing in the seedling roots and replenishing available soil water.

[3]Jenkinson, James L. Data filed 1979. Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

When planted within the planting window, properly conditioned seedlings of both local and nonlocal sources will survive equally well *(table 4)*, even in diverse climatic regions *(table 5)*. Although first-year mortality may be rare in such offsite plantings, other evidence decisively shows that good growth and survival to harvest age are never achieved when planted seedlings are genetically out of tune with the local climate. For example, in some older wildfire plantations in northern California, genetically maladapted ponderosa pine grew poorly, froze severely, and had to be cleared for replanting. In the altitudinal races test of ponderosa pine in the western Sierra Nevada, high-elevation sources planted at low and middle elevations were still growing poorly after 29 years, but at high elevation were more than equalling the rapid growth of middle-elevation sources; low-elevation sources at the high elevation had significant mortality, lean and breakage after 20 years (Conkle 1973, Echols and Conkle 1971). Similarly, in the earliest of provenance trials in the Pacific Northwest, maladapted sources of Douglas-fir initially survived well, but grew slowly, showed freeze damage, and ultimately finished with high mortality 30 to 50 years after planting (Campbell 1975, Silen 1978).

The planting times for established seedlings, on sites sampling 7000 ft of elevation in the Sierra Nevada, illustrate the dependence of the planting window on local climate *(table 6)*. Near the toe of the western slope, the planting window may span up to 10 weeks in the calendar period of January to March. With increasing elevation, the window narrows and opens later. From 2000 ft to snow line near 3500 ft, the window is open for 6 to 8 weeks in February-March. From snow line to 4500 ft, it is 4 to 6 weeks in March-April. To 6000 ft, it is 2 to 4 weeks in April-May. At the highest elevations and anywhere else that snow melts late, the window is 2 weeks and less in May-June. South slopes usually warm 2 or 3 weeks earlier than north slopes, and the windows open accordingly.

For sites below snow line in the western Sierra Nevada, late-winter lifting and immediate planting of seedlings grown on Fruit Ridge can ensure excellent survival. Even in early March, the root growth capacity of most sources is still enough to justify outplanting, but only if climate at the site enhances root growth. With root elongation underway, RGC plummeting, and bud break incipient, no lifting is acceptable beyond mid-March.

For sites above snow line, seedlings must be held in cold storage until the snowpack has melted. For any site buried under snow, seedlings lifted in midwinter and held at 1°C (34°F) are safer than seedlings lifted in early spring when RGC of every source is decreasing. When lifted and stored just before RGC peaks, ponderosa pine from the western Sierra will retain high RGC through at least 3 months (Stone and Jenkinson 1971).

For most sources of ponderosa and Jeffrey pine from northern California, RGC peaks in late January on Fruit Ridge, so seedlings for spring planting are best lifted in the period from early December to February. When planting is synchronized with warming soil trends, sources from both sides of the Sierra Nevada can be lifted through late February—right to the time that roots resume growth in the nursery bed. In my tests, such seedlings were quickly established at 500, 3400, 4500, and 6600 ft of elevation, after 2, 6, 5, and 12 weeks of cold storage, respectively.

For sources from southern California, the second peak of RGC typically occurs in early February, suggesting late January-early February as the best time to lift seedlings destined for the southern forests. For the one exception (J SBer 5660), late February-early March is the indicated time. Whether the first peak is maintained in storage, and whether storage increases RGC from the winter low, has not been determined for any source with a bimodal type of seasonal pattern.

Sources that have a bimodal or plateau pattern suggest that some seedlings grown in the Fruit Ridge climate could be outplanted in fall. Although sources from east of the Sierra crest show high RGC in November (P Eld 6300; J Eld 6400, 8200; W NE-Wash 8000), fall planting is still contingent on sufficient rain to break the summer drought and return soil water contents to field capacity. Further, survival depends on early snows to cover the seedlings and prevent physiological drought. The fall planting window is narrow at best, and in some years it may never open.

Table 6—*Planting times and field survivals of western yellow pines in the Sierra Nevada*

| Site | | Seedling survival[1] | | |
|---|---|---|---|---|
| Locality | Elevation | Ponderosa pine | Jeffrey pine | Planting time |
| | *Feet* | *Percent* | | |
| Beale AFB[2] | 200 | 89 | 97 | Early February |
| Salmon Falls | 500 | 92 | 90 | Early March |
| Garden Valley | 1900 | 98 | 99 | Late February, mid-March |
| Fruit Ridge[3] | 3000 | 95 | 95 | Mid-February, mid-March |
| Mt. Danaher | 3400 | 97 | 98 | Late March |
| Lincoln Hill | 4500 | 96 | 99 | Mid-April |
| Angora Creek | 6600 | 98 | 96 | Mid-May |

[1]Average of several sources, adjusted for mortality caused by gophers and grass.
[2]Personal communication from G. K. Parks, Pacific Southwest Region, Forest Service, Placerville, Calif.
[3]Unpublished data on file at Pacific Southwest Forest and Range Experiment Station, Berkeley, Calif.

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Seedlings of 27 sources of western yellow pines, selected in climates typical of the species, were raised in a nursery in the western Sierra Nevada. Seedling top and root growth capacities were periodically assessed during fall and winter, and field survivals of outplanted seedlings were evaluated in different climates with summer drought. In the nursery, four distinct, innate seasonal patterns of root growth capacity were defined in ponderosa pine from within and outside California, and two distinct patterns were defined in Jeffrey pine. Below snow line in the western Sierra Nevada, seedling survivals were higher in spring plantings than in a winter one, and for California sources than for others. In spring plantings above snow line, survivals for diverse local sources of ponderosa and Jeffrey pines were uniformly high, both on the western slope and east of the Sierra Nevada crest. The results demonstrate that seedlings of any source will have adequate growth capacity and will survive the first year on any well-prepared site if they are lifted at the right time, stored properly, and planted in phase with warming soil trends.

*Retrieval terms: Pinus ponderosa, P. washoensis, P. jeffreyi,* genetic variation, genotype-environment interaction, progeny tests, seedling growth, seedling survival, artificial regeneration